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Improved Mobile Kitchen Unit

Aaron B. Sabbs
Worcester Polytechnic Institute

Conor Daniel Hennessey
Worcester Polytechnic Institute

Neil Anthony Innarelli
Worcester Polytechnic Institute

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THE IMPROVED MOBILE CAFETERIA UNIT

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by:

Conor Hennessey   Aaron Sabbs   Neil Innarelli

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Approved

Prof. M. S. Fofana, Advisor

Mechanical Engineering Department

Abstract

The purpose of this project was to design a mobile kitchen that economically addresses the problems found in current mobile kitchens, while maintaining an attractive and functional package. To do this, we investigated current mobile kitchens to identify their flaws, and how to correct them. We used this information to design a model kitchen unit that addresses these concerns, and selected equipment and appliances that will make the unit safe, sanitary and economically desirable.

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Acknowledgments

Our IQP group would like to thank Professor Fofana for his support, understanding and creativity. Professor Fofana motivated us to produce an end product that we would be proud of, and provided us with the resources to accomplish this end.

CHAPTER 1. IMPOVEMENT OF MOBILE FOOD PREPERATION UNITS

1. Introduction

Current mobile food preparation kitchens suffer from many serious flaws which undermine their safety, productivity and profitability. Most commercial mobile kitchens available today are merely pre-fabricated trailers or campers which have been filled with kitchen equipment, rather than being designed from the beginning as a functional unit. Because of this lack of focused design, they can be unsanitary, uncomfortable and unsightly. Each year, preventable food-borne illnesses and work related injuries take a large toll on our economy, in both monetary and human costs. Our group aims to help reduce these costs by carefully engineering a better mobile cafeteria.

Our project objective is to propose a new and innovative design of a mobile food preparation unit. Through this design we intend to address problems found in current mobile kitchens in an attractive and functional package. Our primary goal is to develop these kitchens with a focus on sanitation and preventing worker fatigue, and to produce a multi-functional unit that can do more than just provide food and beverages in an efficient manner.

The most crucial constraints for our project are mobility, size and functionality. The kitchen must be able to be moved quickly and easily, which means weight will be another important factor. It must also be large enough to hold all the necessary equipment and supplies while being small enough to fit on a crowded city street. It is also important that the kitchen is within the price ranges of the vendors that would look to purchase it.

This project aims to increase the safety of both mobile cafeteria workers and consumers in various ways. The first is by increasing sanitation and reducing cross-contamination of food, therefore reducing the prevalence of food-borne diseases. Furthermore, the project will increase employee safety by reducing fatigue related injuries through careful design of kitchen components and control of working environment. This reduction of worker fatigue will also reduce the likelihood of food contamination through careless and unsanitary worker behavior. We also desire to address the aesthetics of current mobile kitchens. The problem with current designs is their boxy shape and ungainly ventilation protrusions. In our design we seek to produce a kitchen with a sleek exterior design that blends seamlessly into the city, and is pleasing to behold.

We intend to incorporate many cutting-edge technologies, materials, and component designs into our mobile kitchen. Specifically, we aim to integrate ordering and purchasing food with electronic devices, such as phones and laptops. This will streamline the process, eliminating mistakes and increasing customer satisfaction. Our goal is to allow the customer order and pay on their mobile device, and pick up their order when they arrive at the kitchen's location. We will also incorporate new advertising technologies to offer the kitchen's owner additional sources of revenue. These advertising technologies include LCD displays, scrolling advertisements and the use of viral marketing and social networks.

Our report will include background information on current mobile kitchens, research on specific engineering methods related to improving health and safety, and design proposals for the two mobile kitchens. This will be followed by schematic drawings and detailed descriptions of the systems and components within our kitchen.

CHAPTER 2. MOBILE KITCHEN DESIGN FACTORS

2. Introduction

To design a well-functioning kitchen is a difficult task. There are many factors that influence how effective a particular kitchen is, and they interact in a complex manor. The most important factor to consider in the design of a kitchen is the interaction between workers and the workplace. A poorly designed workplace can make employees less productive both directly and indirectly. Directly the workplace can slow the movements of workers and increase the time it takes to complete tasks, and make these tasks more difficult. Indirectly, a poorly designed workplace can cause fatigue, which increases mistakes and lowers productivity. Fatigued workers are more likely to neglect sanitation, which is an extremely important aspect of any kitchen. The critical relationships between food safety, employees and the workspace are summarized in Figure 1. We will devote our second chapter to discussing the factors that are important to kitchen design, and how they can be best designed to maximize productivity, safety and comfort.

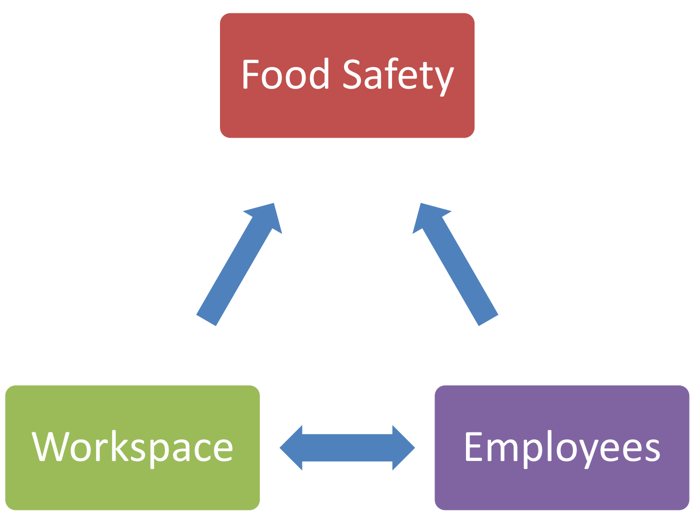


Figure 1. Factors Affecting Food Safety

2.1 The Building Environment

Mobile Kitchens are notorious for their poor working environment, whether it's inadequate lighting, cramped conditions, poor temperature control or improper ventilation. These factors place both physical and mental stress on employees, reducing output and employee morale, and increasing turnover and mistakes. These mistakes can cause food to become contaminated, leading to illness and even death. In our design proposals we intend to address these issues, and create a kitchen with an excellent working environment which enhances both comfort and safety.

Overall indoor environmental quality (IEQ) is the measure of all factors affecting the workplace environment. Improving IEQ is one of the most cost-effective ways of enhancing employee satisfaction, productivity, and profitability. These enhancements can be direct, such as an increase in product output or quality, or indirect through the reduction in sick days, mistakes and absenteeism (Fiske, 23). The quality of a workplace environment is made up of many pieces, each of which contribute or subtract from an employee's comfort and productivity. By improving the parameters that constitute the workplace environment, large gains in employee output can be realized at little cost. These environmental factors include layout, equipment ergonomics, lighting, air-flow, temperature, humidity, and noise levels. Generally, air-flow, humidity and temperature are combined into the category of indoor air quality (IAQ). Each of these environmental factors will be discussed later in greater detail. The environmental factors mentioned will each be discussed within the chapter that follows

Numerous studies have shown that worker costs make up the largest fraction of total costs. For the average office building, the ratio of building operation costs to average salary costs is 1:13.7 (Lomonaco and Miller, 2). This means that for the average office building office building a 1% increase in worker productivity is equivalent to a 13.7% increase in building efficiency. Although the ratio of worker costs to building costs would be larger for a smaller building such as a mobile kitchen, the principal remains the same: low cost improvements in working environment produce a large return on investment through improvements in productivity.

In a comprehensive analysis studies done on environmental satisfaction and productivity, Lomonaco and Miller concluded that when numerous environmental factors are examined together, they can have a productivity impact of as much as 15% to 17% of employee salary. Approximately 75% of this increase was realized through improvements in IAQ, lighting and noise levels, with the remaining due to improved layout and ergonomics. Similar improvements in productivity have been seen in building upgrades encompassing lighting and HVAC systems (Romm and Browning, 14). These percentages represent very significant contributions to a business' bottom line.

2.1.1 General Layout Considerations

In order to maximize both worker efficiency and usable space, the mobile kitchen must be well organized. Distances between work centers that are often used simultaneously should be minimized to limit walking distances. The flow of materials through the kitchen should be scrutinized so that they aren't constantly moved back and forth across the kitchen.

A flowchart is used to help visualize the relationships between the different areas of the kitchen. This allows the designer to see which equipment and storage areas should be close to each other. Figure 2 shows these relationships and allows the designer to visualize the flow of materials.

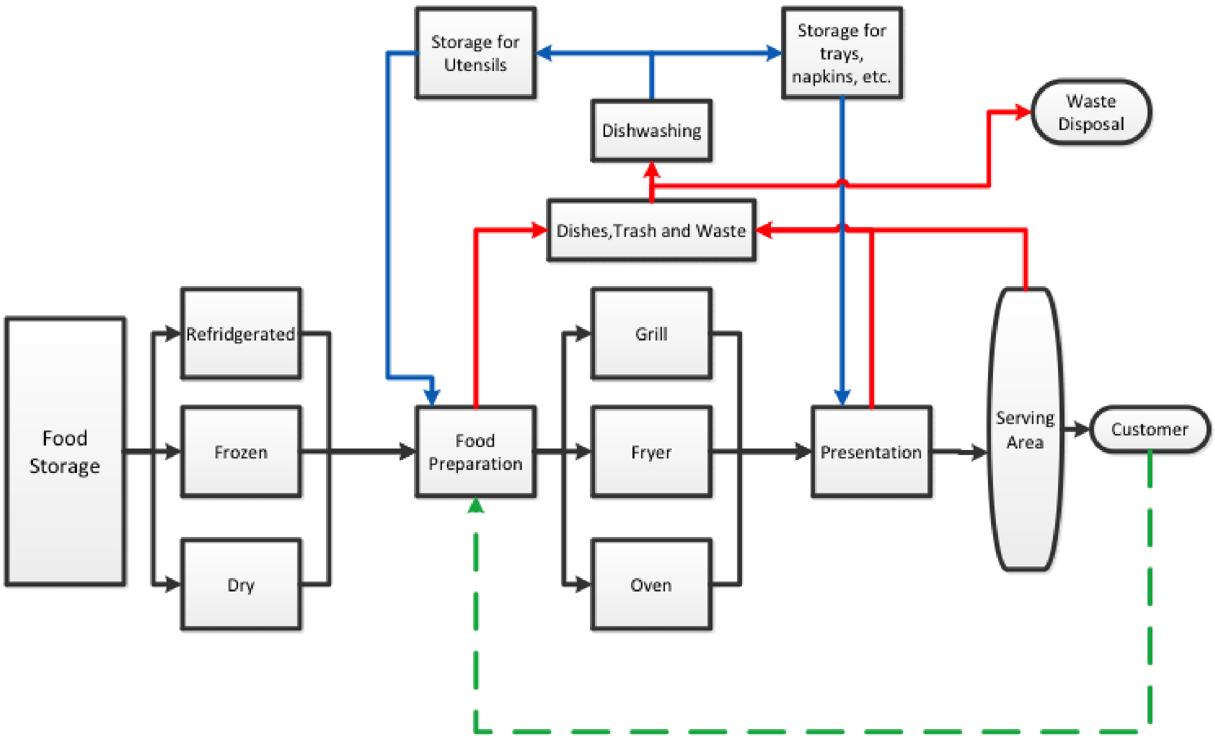


Figure 2. Flow Chart of the Mobile Kitchen Process

In Figure 2, the relationships between the different areas of the kitchen are shown. Areas directly connected should be constructed in close proximity to each other in order to maximize efficiency. Black arrows represent the flow of food and ingredients, beginning in food storage and ending at the customer. Red arrows represent the flow of waste and used dishware, where the waste is disposed of and the dishware is washed. Once washed, blue arrows represent the dishware, where it enters back into the cycle.

The food preparation process begins with food storage, where ingredients are kept in refrigerators, freezers, or pantries, depending on the type. The ingredients are brought to the food preparation area, one or more countertops, where they are combined before being cooked. The grill, fryer, oven, and other cooking equipment should each be in close proximity to the food preparation station, but not necessarily close to each other. Once cooked, the food must be made ready to present to the customer, along with dishes, utensils, and napkins.

Dishware, utensils, and other washable items are used in a cycle. They are taken from storage, used to prepare or serve the food, and washed before returning to storage. Disposable items such as paper products are simply taken from their storage and disposed of after they are used.

One of the most important yet often overlooked relationships that must be considered is that between the customers placing their orders and the cook. However, the customer does not necessarily need to be close in proximity to the cook or even the food preparation area. There are multiple ways for the order to be communicated to the cook without the customer actually being physically close to them.

The shortage of available space requires the mobile kitchen to be designed in a way that maximizes usable space. Some traditional layouts that maximize usable space as well as the efficiency of the cook are the single-wall layout and the U-shaped layout. These layouts are traditionally implemented in standard kitchens; however, they are thin enough to be utilized in a mobile kitchen.

2.1.2 Single-Wall Layout

The single-wall layout will maximize space while still allowing the mobile kitchen to have a large serving-window that takes up the majority of one side. The main storage and cooking equipment is located opposite the window, with other storage available beneath the window. This layout is economical, and ideal for a single user. (Woodson, Tillman and Tillman, 214) It gives the user the ability to access cooking equipment and storage while allowing the customer to view the food preparation. Figure 3 shows a simple single-wall layout including an oven, sink, and refrigerator.

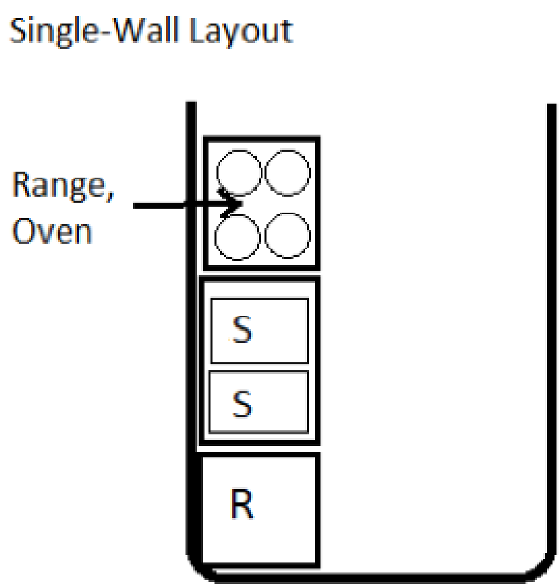


Figure 3. Example of the Single-Wall Layout

2.1.3 U-Shaped Layout

The U-Shaped layout is an efficient arrangement for a kitchen that has enough space to allow an aisle between rows of cabinets and equipment. This layout allows much of the cooking equipment to be placed at an end of the mobile kitchen, leaving the other end available for storage and the serving window. In order to use this layout efficiently, it must minimize walking distance between work centers that multiple cooks can use simultaneously (Woodson, Tillman and Tillman, 214). Figure 4 shows a standard U-shaped layout, consisting of an oven, sink, and refrigerator.

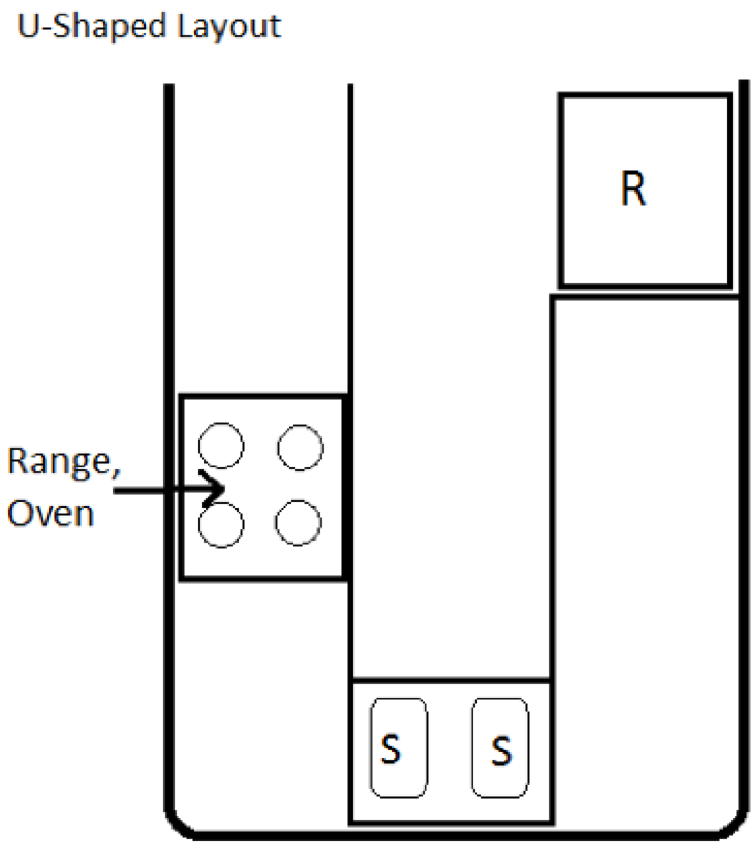


Figure 4. Example of a U-Shaped Layout

2.1.4 Work-Triangle Concept

The work triangle is a traditional arrangement that limits walking distances between the main work centers of the kitchen. This allows the cook to easily move between the areas that are commonly used and limit time wasted by walking around the kitchen. In the average kitchen, the three main work centers are the range, refrigerator, and sink. To optimize efficiency, the walking distances should be no more than 22 feet (Woodson, Tillman and Tillman, 214). A sample work-triangle is shown in Figure 5, illustrating the distances the between each of the main work centers.

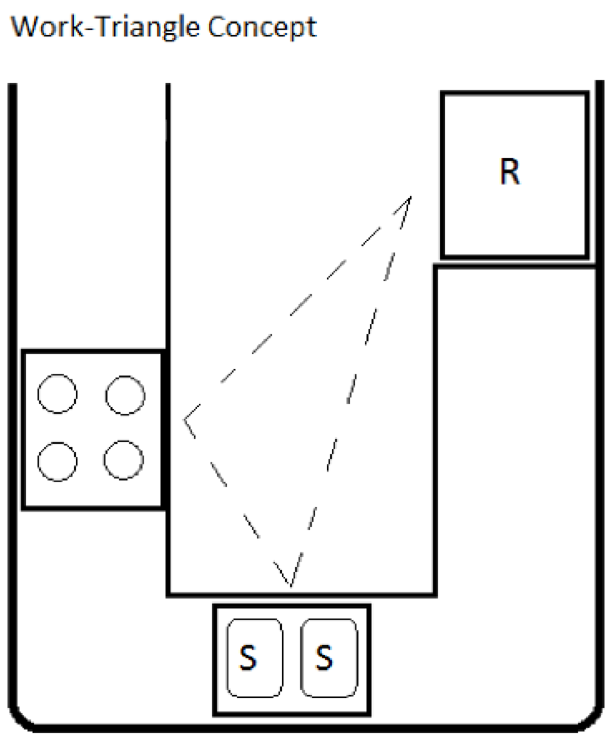


Figure 5. Example of the Work-Triangle Concept

2.1.5 Optimal Kitchen Dimensions

Constructing the mobile kitchen with counters, sinks, and other areas as close as possible to optimal working heights will allow the workers to be comfortable as they perform their daily tasks. This will reduce the physical exertion required of the workers and allow them to work efficiently. Table 1 gives comfortable working heights for common kitchen surfaces.

Table 1. Comfortable Working Heights

Area	Height (in)
Mix-center counter	32
Bottom of Sink	33
Highest Shelf Fully Visible	61
Without Obstruction	72

Wall Oven	32-34
Lap Table	24-26
Chair	16

(De Chiara and Callender, 217)

Figures 6 through 8 identify typical guidelines for kitchen counter dimensions. These guidelines provide the dimensions for clear counter space adjacent to different equipment. These dimensions will provide the kitchen with sufficient counter space to prepare food and do other routine functions.

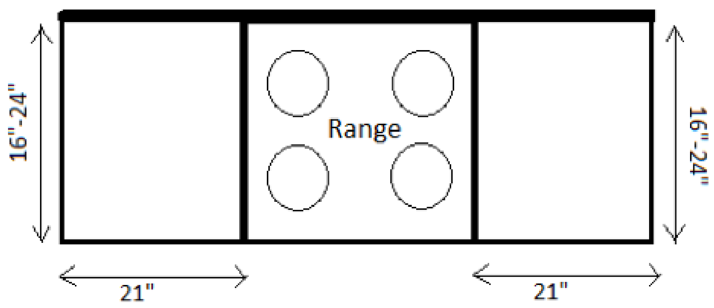


Figure 6. Typical Minimum Dimensions for Counter Adjacent to Range

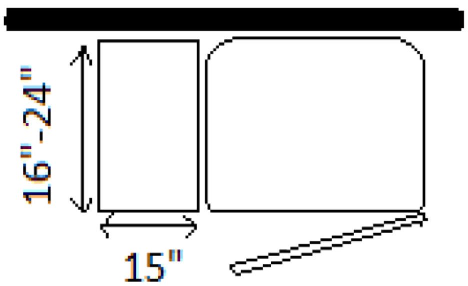


Figure 7. Typical Minimum Dimensions for Counter Adjacent to Refrigerator

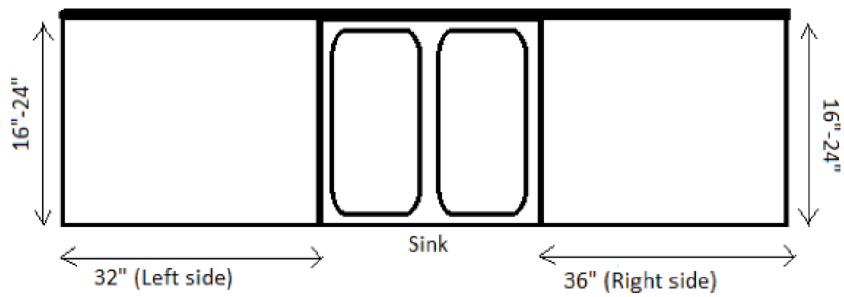


Figure 8. Typical Minimum Dimensions for Counter Adjacent to Sink

2.2 Ergonomics

Proper design of workplace ergonomics is very important for many reasons. Ergonomic design improves worker production, decreases worker discomfort, and accommodates users of all sizes. A workplace not designed with the employee in mind can cause fatigue, which increases mistakes and lowers productivity. These mistakes can compromise food safety and place consumers at risk.

Therefore, our kitchen will incorporate ergonomic design into all aspects of the workspace, from counters to equipment. More detailed information on incorporating ergonomics into design to prevent fatigue can be found in Section 2.7.

2.3 Lighting Design

A well-designed lighting system is an important piece of any well designed work or living area, and is a more complicated subject than many believe. Light quality can be affected by many factors such as light level or intensity, glare, and shadows. It is because of these factors that more illumination will not necessarily result in improved task visibility; a given space light can be too bright as well as too dim (Woodson, 322). Numerous studies have documented the effects of improved lighting on performance. In one particular study done by Romm and Browning, lighting retrofits and increased daylighting produced significant improvements to productivity, absenteeism and product quality, and had a typical pay-back period of two years. When adjusted for external factors, the average increase in measurable output was almost 10%, and the average drop in absenteeism was 15%. The study also documented an increased volume of sales in aisles of supermarkets making use of natural daylighting.

To understand the proper design of lighting systems requires some familiarity with the applicable units and terminology A footcandle, fc, is a unit of the density of luminous flux over an area. One footcandle is equal to a density of one lumen per square foot, which equal to the illuminance cast on a surface by a one-candela source one foot away. The footcandle is the primary unit used to measure lighting levels in commercial and industrial applications. To give an idea of scale, a dim movie theater has a light level of 0.5-2fc, a typical office building is 50-75fc, and an overcast day approximately 1000fc (Woodson, 322).

The 2009 Food Code specifies a minimum light level of 50 foot candles for any area where a food service employee is working with food or potentially unsafe
utensils and equipment such as knives, slicers, grinders, or saws. The task requirements for food preparation work are medium-detail, fair contrast, prolonged duration and fast, error-free response. For these conditions, Woodson specifies an approximate light level of 50-100fc. These levels are higher than some other recommendations because they provide more than adequate task lighting as well as an additional psychological benefit.

There are many types of commercial light sources available today. Among these are gas discharge devices, light-emitting diodes (LEDs), and incandescent-filament lamps. Due to the short life-span and high energy usage of incandescent bulbs, they are falling out of favor and widespread use, with some states even issuing bans on their use and production. Therefore, we will focus our analysis on LEDs and gas-discharge devices. Many of the lamps within the category of gas-discharge devices (such as Mercury-vapor, metal-halide vapor, high-intensity-discharge, and high-pressure sodium vapor lamps) are used to produce large quantities of light, and are best suited for outdoor or high-bay industrial applications. As such, we will only include florescent and compact fluorescents within our analysis of possible gas-discharge lamps.

LEDs have properties highly suited towards use in mobile kitchens. LEDs are solid state devices, which means unlike normal incandescent bulbs that contain fragile filaments, they are highly resistant to breaking due to shock, vibration and large temperature swings (Abramowitz, 12-88). They are very energy-efficient, produce negligible heat, and lifetimes are not affected by cycling on and off. Unlike fluorescent bulbs, LEDs do not contain Mercury, which can pose a chemical contamination hazard in food preparation areas. Although LEDs have a higher initial cost than most other sources of illumination, they are rapidly becoming more cost competitive as use continues to increase.

Along with glare, another common problem in lighting design is output degradation. It has been estimated that typical lighting output is reduced up to 25% within 6 weeks of installation (Woodson, 323). To prevent this, fixtures must be made readily accessible for maintenance and replacement. Light-filtering panels must also be made of a material that does not discolor with age. Kitchen lighting should be built into or mounted against the ceiling, so that dust accumulation is avoided.

Natural lighting (also referred to as daylighting) has both psychological and aesthetic appeal as well as offering potential energy savings by reducing the amount artificial light needed in a space. Commercial buildings are typically only occupied during the day, and throughout much of the year artificial lighting has the added cost of increasing cooling loads (Kreider and Rabl, 674). Our mobile kitchen will make use of vertical windows for natural ventilation and daylighting, but additional skylights offer the ability to spread light evenly over a large work plane. Avoiding glare is a concern during periods of direct sunlight, and is usually achieved through use of diffuse glazing. Skylights are usually more expensive due to additional waterproofing requirements, but they will be considered in our design.

2.4 Heating, Ventilation and Air Conditioning

The most critical aspect of the workplace environment are the systems that handle heating, ventilation and air conditioning for the workspace which are more commonly referred to as HVAC systems. These HVAC systems are responsible for maintaining an acceptable level of Indoor Air Quality (IAQ) within a given space. IAQ is a measure of contaminants, air-flow, humidity and temperature. Although a part of IAQ, humidity and temperature are usually considered as part of a different parameter, known as thermal comfort.

Thermal comfort is a measure of the fraction of occupants who will find the given environment thermally acceptable. ASHRAE Standard 55 specifies conditions in which a given fractions of occupants will be satisfied, and maximizing this level of satisfaction is one of the main goals of HVAC design and implementation. The major factors influence thermal comfort are air temperature, relative humidity, air velocity, and environment temperature, as well as air turbulence and radiant temperature asymmetry, which are important but play less of a role (Spengler et. Al, 60).

Achieving the highest satisfaction for each individual is usually not possible with one set of conditions because there are such large variations in the perception of thermal comfort, both physiological and psychological, from person to person. To remedy this, recent industry trends have been to provide each worker individualized control of his or her own work space. This individualized control has been shown to increase productivity, but is not feasible for very small spaces such as a mobile kitchen.

Heating and cooling loads depend on the indoor conditions that are to be maintained and on the weather. Therefore, the first step in design of an HVAC system is selection of the design set points for the system. Fortunately, the effects of various parameters on employees and the optimal set points are well-known, and can be found in ASHRAE Standard 55. We will discuss each briefly to identify its importance and possible consequences of not being able to meet set points. It is important to remember that ideal working conditions vary between individuals, and even at conditions widely accepted as optimal, almost 20% of people will still express dissatisfaction.

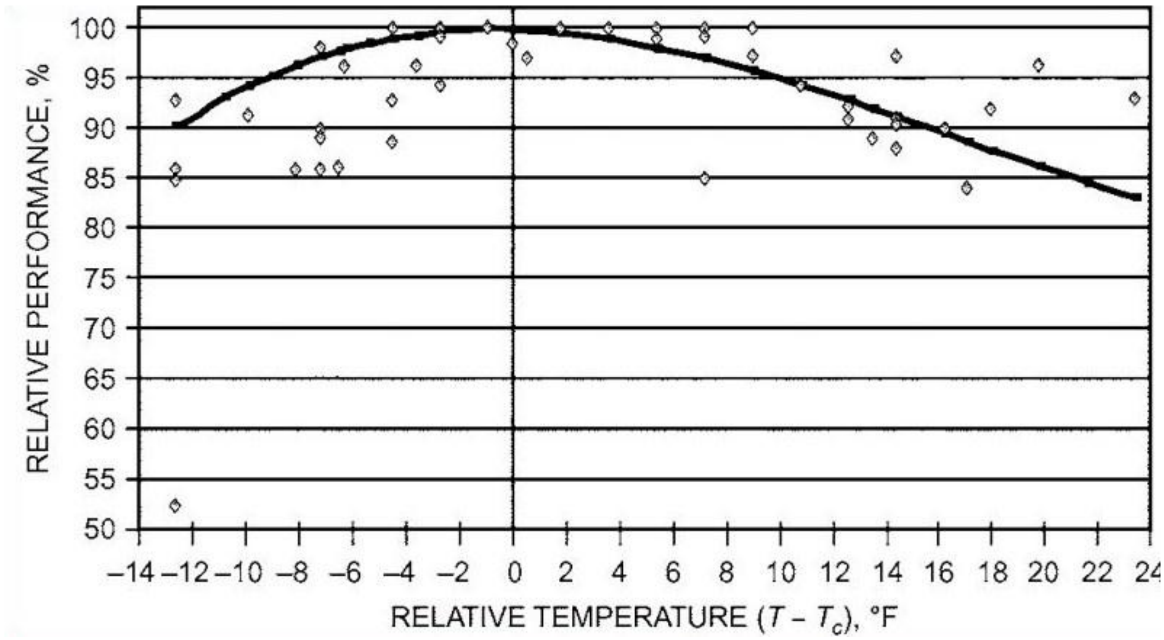


Figure 9. Performance Versus Deviation from Optimal Comfort Temperature (Tc). From ASHRAE Fundamentals 2009

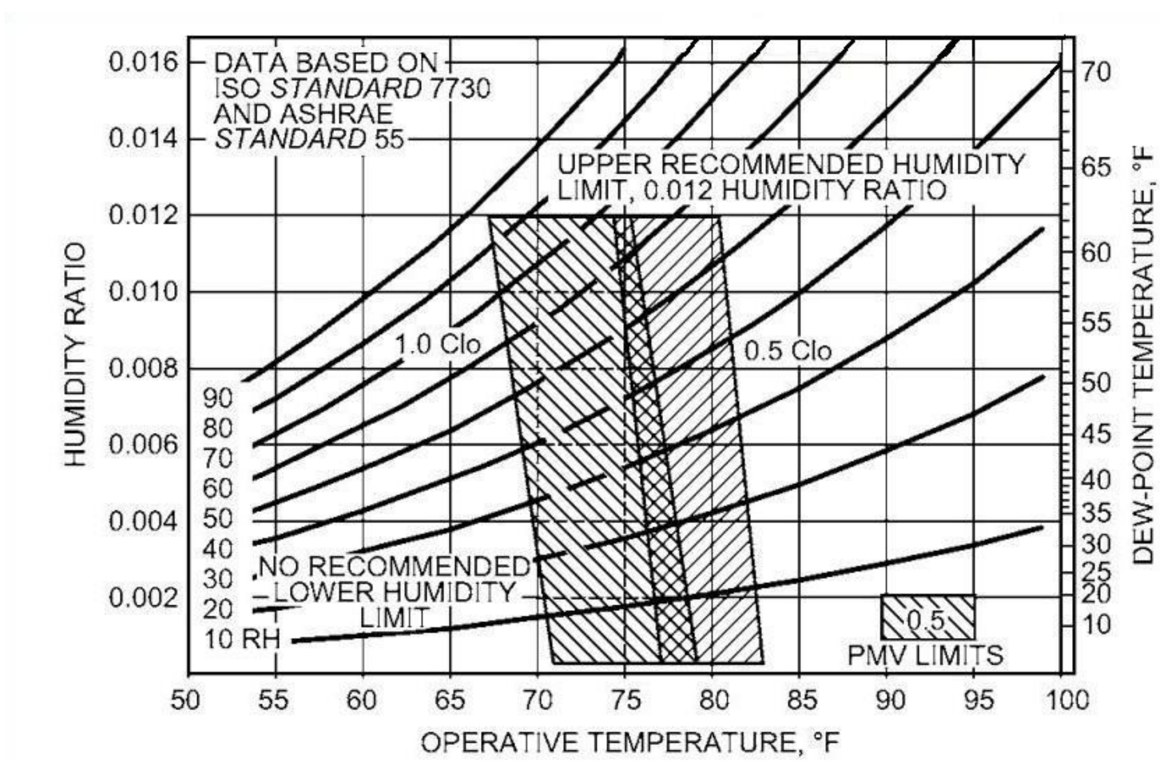


Figure 10. Comfort Zones for Airspeeds less than 40 fpm. From ASHRAE Fundamentals 2009.

2.4.1 Temperature

The perception of a given temperature as comfortable is dependent on many variables. For instance, in a 60°F gym someone sitting in shorts in a t-shirt may feel chilly, while someone wearing a jacket and running would be sweating profusely. In any calculation of the ideal working temperature, it is important to know how much effort workers will be exerting, and how much clothing they will be wearing while doing so. These variables, amount of clothing and physical activity have each been quantified so that such calculations can be made.

The ASHRAE thermal sensation scale is used to quantify a person's perception of the thermal environment and is defined as follows:

+3 hot
+2 warm
+1 slightly warm
0 neutral
-1 slightly cool
-2 cool
-3 cold

The thermal sensation scale is used to develop Predicted Mean Vote (PMV) model for a set of conditions. The PMV model can be used to calculate the predicted percent of people who would be dissatisfied (PPD) in a given thermal environment, based on the assumption that votes of +2, +3, -2, or -3 are expressions of dissatisfaction.

Clothing provides the body with thermal insulation and reduces the effectiveness of sweating by slowing evaporation from the skin. The amount of insulation that clothing provides is typically described in units of **clo,** where one clo has a thermal resistance of 0.155 K m^2/W (Goodfellow and Tahti). To estimate total (clo_t) for an individual one simply sums all the clo values of the individual items worn (clo_i). For kitchen work, the average employee will be wearing underpants, a shirt, pants, a smock and socks and shoes, which totals to about 0.9 clo.

Typical values of clo_i for some common items of clothing are given in Table 2. Motion generally increases the amount of ventilation that reaches the body, thereby reducing the clothing's effective insulation. This change in a outfit's insulation value (Δclo_t) can be estimated from the clothing's value of insulation at rest (clo_t) and the walking speed (S), in steps per minute:

$$\Delta clo_t = -(0.504)(clo_t) - (2.81E\text{-}3)(S) + 0.24$$

For kitchen work, the average employee will be wearing underpants, a shirt, pants, a smock and socks and shoes, which totals to 0.9 clo. While the employee is moving about the kitchen at a pace of 50 steps per minute, the effective insulation value of the clothing will be about 0.55 clo.

Table 2. Clo Values for Items of Clothing ($k*m^2/W$) (Adapted from Goodfellow and Tahti)

Item	Clo_i	Item	Clo_i
Pants (thin)	0.15	Underwear	0.05
Athletic shorts	0.08	Long-sleeved work shirt	0.25
T-Shirt	0.09	Thick sweater	0.36
Ankle-length socks	0.02	Thick Jacket	0.7
Coveralls	0.49	Shoes	0.03

When choosing optimum conditions for health and comfort, the typical rate of work done by space occupants must be known, because metabolic heat output is a function of exercise intensity; the more intense the activity, the more heat generated by the body. This heat is generated by the contraction of muscles, which convert about 15% of the energy they expend as useful work, and the rest as heat.

Table 3. Typical Metabolic Heat Generation for Various Activities

Activity	Heat Generation (W/m^2)	Heat Generation (met)
Sleeping	40	0.7
Reclining	45	0.8
Writing	60	1.0
Standing, relaxed	70	1.2
Walking about	100	1.7
Cooking	95-115	1.6-2.0
Calisthenics	200	3.0-4.0
Handling 100lb bags	225	4.0
From ASHRAE Fundamentals 2009		

Determining the ideal temperature range can be done graphically by using Figure 10 of comfort zones for airspeeds less than 40 fpm. The figure gives the comfort zone boundary temperatures (T_{min}, T_{max}) for values of .5 and 1 clo, at various relative humidities. Near the upper and lower limits of the comfort zone, the PMV on the ASHRAE thermal sensation scale would be +.5 and -.5, respectively. The graphical interpretation is valid for people with metabolic heat generation levels of approximately 1.2 met, or 70 W/m^2. The values of T_{min} and T_{max} should be decreased by 2.5°F per additional met output over 1.2 met, and decreased by 1°F for each additional .1 clo worn by workers. For a kitchen worker with a maximum heat generation of 2 met and a clo_t value of .9, the ideal temperature range at 50% relative humidity would be 68°F to 75°F.

For more detailed steady-state calculations, the PMV-PPD model can be solved iteratively with a computer. For transient conditions, the Two-Node model is used to calculate PPD and PMV. These models and calculations are discussed in detail in ASHRAE 2009 Fundamentals.

2.4.2 Humidity

Humidity is the measure of the amount of water vapor in the air, and has a pronounced effect on thermal comfort at high and low relative to the maximum. The ratio of absolute humidity to the maximum absolute humidity is referred to as relative humidity, and can be easily calculated using a psychrometric chart and a known set of conditions, such as temperature. At high levels of relative humidity, the rate of evaporation from the skin is low which makes perspiration ineffective. This leads to high levels of skin moisture, which is uncomfortable and leads to increased friction between the skin and clothing. Therefore, it is recommended that relative humidity not exceed 62% on the warm side of the ASHRAE comfort zone, which corresponds to a upper humidity ratio limit ($lb_{water\ vapor,max}/lb_{dry\ air}$) of 0.012.

Low levels of humidity typically do not affect thermal comfort, but are important from the standpoint of other comfort factors. Very low humidity leads to skin drying, irritation of mucus membranes, dryness of the eyes, static electricity generation, and increased incidence of absenteeism and respiratory illnesses. It is therefore recommended that the dew-point temperature of occupied spaces not drop below 36ºF.

The other factors affecting thermal comfort are due to thermal non-uniformity. This occurs when a person is thermally comfortable on the whole, but one or more parts of the body are too cold or hot. These sources of non-uniformity include an asymmetric radiant field, local convection cooling (drafts), vertical air temperature differences or contact with a hot or cold floor. Each of these factors can be analyzed individually, but the main method of mitigation is reducing temperature gradients, with the goal being to achieve temperature uniformity.

2.4.3 General Ventilation

In most buildings, variable air volume (VAV) mechanical ventilation is used to maintain thermal comfort level and acceptable IAQ. Properly designed and installed VAV mechanical ventilation systems have the greatest potential efficiency and control of air exchange as they can adapt to changing thermal loads (ASHRAE Fundamentals Handbook 2009). In smaller buildings, such as a mobile kitchen, the use of natural ventilation is possible, although some precision in the control of thermal comfort is sacrificed, especially in very hot or cold climates. Natural ventilation is typically achieved through the use of operable windows, which allows the end user some direct control of indoor air temperature and contamination levels. Direct end user control of the workplace environment has been shown to improve both productivity and satisfaction, as employees can quickly adapt to changing conditions and tailor the workplace to their individual needs (Lomonaco and Miller). Employees seated near windows also have lower levels of complaints about their workspace. However, employee operable windows can come at a significant energy cost if opened while heating or cooling equipment is running. Purely natural ventilation systems are also limited by reliability issues, as they are dependent on outdoor conditions which change frequently.

ASHRAE 2009 Fundamentals Handbook provides several useful tips for the design of natural ventilation systems. For hot, humid climates, the use of mechanical cooling systems is recommended. However, if this is not possible air velocity in the space should be maximized. For hot, dry climates, it is possible to use evaporative space cooling. The building should be designed to give maximum exposure to breezes, making use of large openings. Parapets, wing walls and overhangs can also be used to funnel breezes into openings. If there is no prevailing wind, or the structure is mobile and will be deployed in differing orientations, all openings must be designed to provide ventilation regardless of wind direction.

Windows should be located in opposing pressure zones, such as on each side of the building to maximize airflow. These windows must be fully accessible by building occupants unless they are automated. If there is only one external wall, airflow is maximized by having two large, widely spaced windows. There should be vertical distances between openings to take advantage of the stack effect; the greater the vertical distance, the greater the ventilation. Natural ventilation rates are maximized by having inlets and outlets of approximately equal area. Smaller inlets will create high inlet velocities, while smaller outlets produce lower but more uniform air velocities in the space.

In our mobile kitchen, we intend to make use of both mechanical and natural ventilation with a hybrid or mixed mode system. These hybrid systems offer both flexibility and high energy efficiency, and are rapidly gaining favor. The design of hybrid systems is particularly complex and their use has become more widespread with the advent of integrated multi-zone airflow and thermal modeling. To have an effective hybrid system requires a large degree of control of both the mechanical and natural systems, which can be achieved through careful design and planning.

2.4.4 IAQ, Contaminants and Exhaust Hoods

Within the typical building environment the contaminants affecting IAQ are numerous and have many sources. They can be external, such as nearby traffic and smog, or internal such as off gassing volatile organic compounds (VOCs). For a small mobile kitchen, the biggest source of IAQ degrading air contamination will likely be due to cooking equipment, such as a grill or fryer. To control IAQ contaminants, three methods are generally used: source removal, local source control and dilution (Spengler et. Al, Ch 5). For the purposes of an indoor kitchen, source removal is difficult while maintaining functionality, so local source control and dilution offer the most effective ways to control levels of contaminants. Dilution is achieved by sufficient levels of general ventilation, which is the intentional introduction of outside air into a space through natural or mechanical means. Unintentional leakage of air through cracks and openings, known as infiltration, also helps dilute contaminants and prevents buildups.

Local source control is the preferred design feature to improve IAQ in kitchen environments, and is basically the use of a separate, local exhaust system designed to remove contaminants from a source (Spengler et. Al, 87). Examples of local source control are laboratory fume hoods or exhaust fans in bathrooms. For kitchens, most heat and contaminate producing equipment, such as grills and fryers, are typically placed under exhaust hoods. The purpose of these hoods is to cooking effluent from equipment, keeping employees comfortable and safe. Buildup of cooking effluent, especially combustion by-products like carbon monoxide can be dangerous and even fatal to employs without proper ventilation. To design a well-functioning kitchen ventilation system requires some background knowledge on the behavior and nature of cooking effluent.

In commercial kitchens, cooking effluent produced by equipment includes combustion products from fuel, excess heat and gaseous, liquid, and solid contaminants produced by the cooking process. The gaseous, liquid and solid by-products of the cooking process consist mainly of grease and water vapor. The amount of grease in the vapor phase of released effluent is significant and varies from 30% to over 90% by mass (ASHRAE 2007 Handbook). A breakdown of plume composition by size and phase for various equipment and foods is shown in Figure 11.

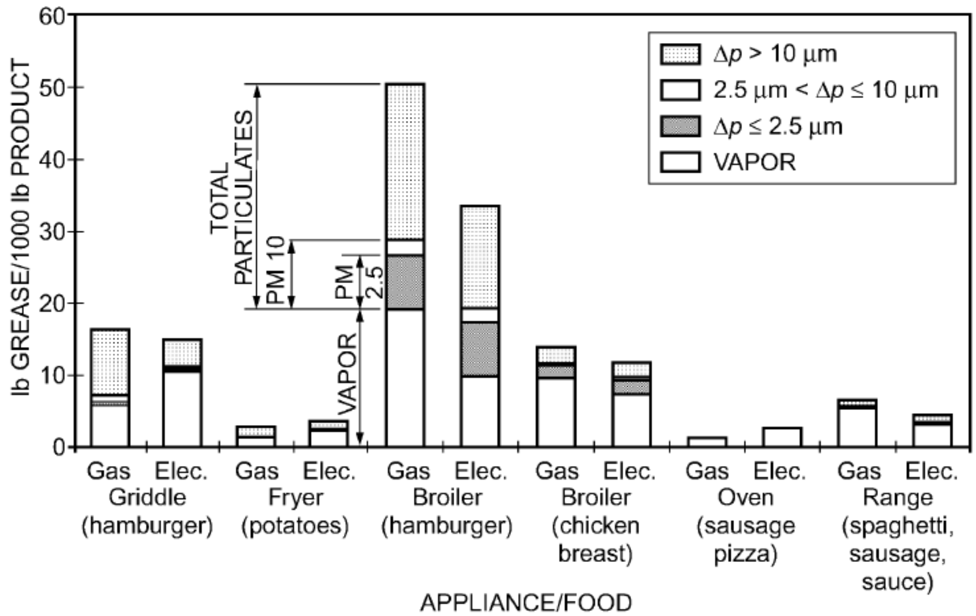
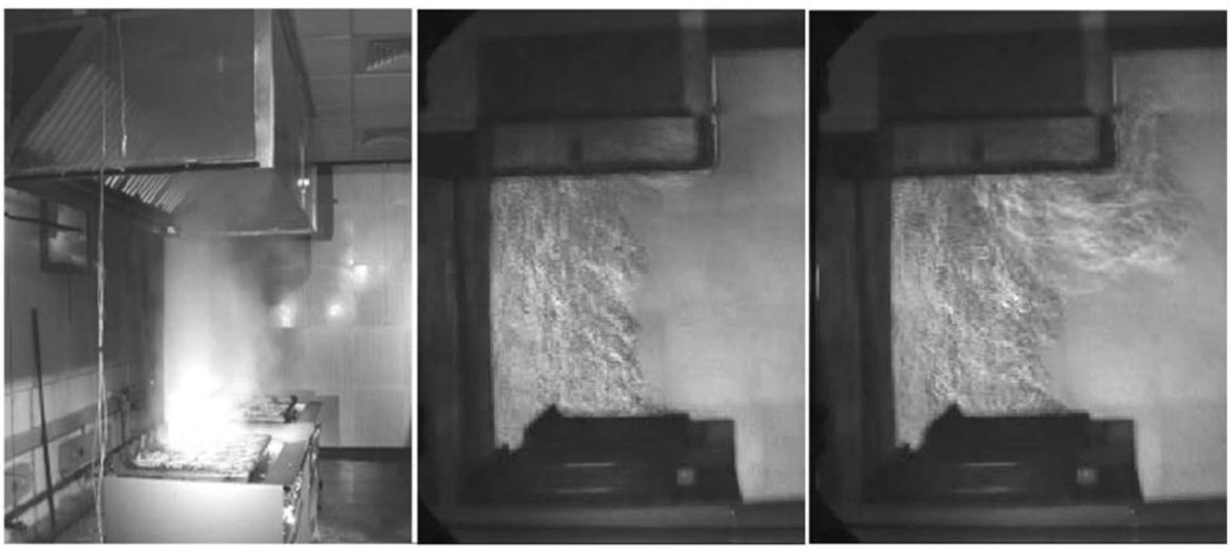


Figure 11. Grease in Particle and Vapor Phases Emitted by Cooking Appliances

The contaminants produced by the cooking equipment are usually entrained in a plume of hot air rising from the equipment. This thermal plume contains approximately 50 to 90% of the energy that was originally input into the given appliance (ASHRAE 2007 Handbook). The rest of the appliances energy is lost as heat through radiation which is largely unaffected by local ventilation and must be removed by the HVAC system. Without interference from air currents, a heated plume will rise vertically, entraining additional air as it does so. This additional air enlarges the plume and lowers its temperature and velocity. If the plume is located near a flat surface such as a wall, the plume will be drawn close to the surface through the Coandă effect. This effect can be used to direct the thermal plume into the hood by locating cooking equipment close to a wall.

Exhaust hoods are placed above the cook surface so that the rising plume, which is more buoyant than the surrounding air, flows into it. The hood must have an exhaust rate must be slightly higher than the volumetric flow rate of the plume, and be large enough to accommodate the expanding plume. If there are significant cross-currents within the space, the hood exhaust rate must be higher to compensate and prevent fumes from spilling out. This spill over is shown in Figure 12 which compares the effects of different exhaust flow rates for given conditions using Schlieren photography. The test setup was two char broilers under an 8 ft long wall-mounted canopy hood, cooking hamburgers, and is shown in Fig.12.A. In Fig.12.B. the exhaust rate of the hood was set to 4400cfm and the hood achieves full containment. In Fig.12.C. the exhaust rate is lowered to 3300cfm, and there is significant loss of containment.



A B C

Figure 12. Thermal Plume from Cooking Appliances Under Wall-Mounted Canopy Hood

Electric equipment such as warming and holding ovens, coffee makers and toasters do not typically require exhaust hoods.

Exhaust hoods are categorized into two distinct types: Type I hoods remove grease and smoke, while Type II hoods are not. Type I hoods are required over equipment that produces smoke and grease vapors, such as griddles, broilers, and ovens. For a hood to be classified as Type I, it must have baffles, filters or some means for removing grease vapor and particulates, as well as fire suppression system. Type II hoods remove steam and heat and are used in less demanding applications than Type I hoods, such as over dishwashers. A Type I hood can be used in place of a Type II hood, but a Type II hood cannot be used in situations requiring a Type I hood. Exhaust hoods are further separated into different styles as shown in Figure 13.

Another important consideration in the design of an exhaust hood is the necessary flow rate for the application. The ASHRAE Handbook provides detailed information on required flow rates and safety factors for common kitchen applications, broken down by hood type and equipment type.

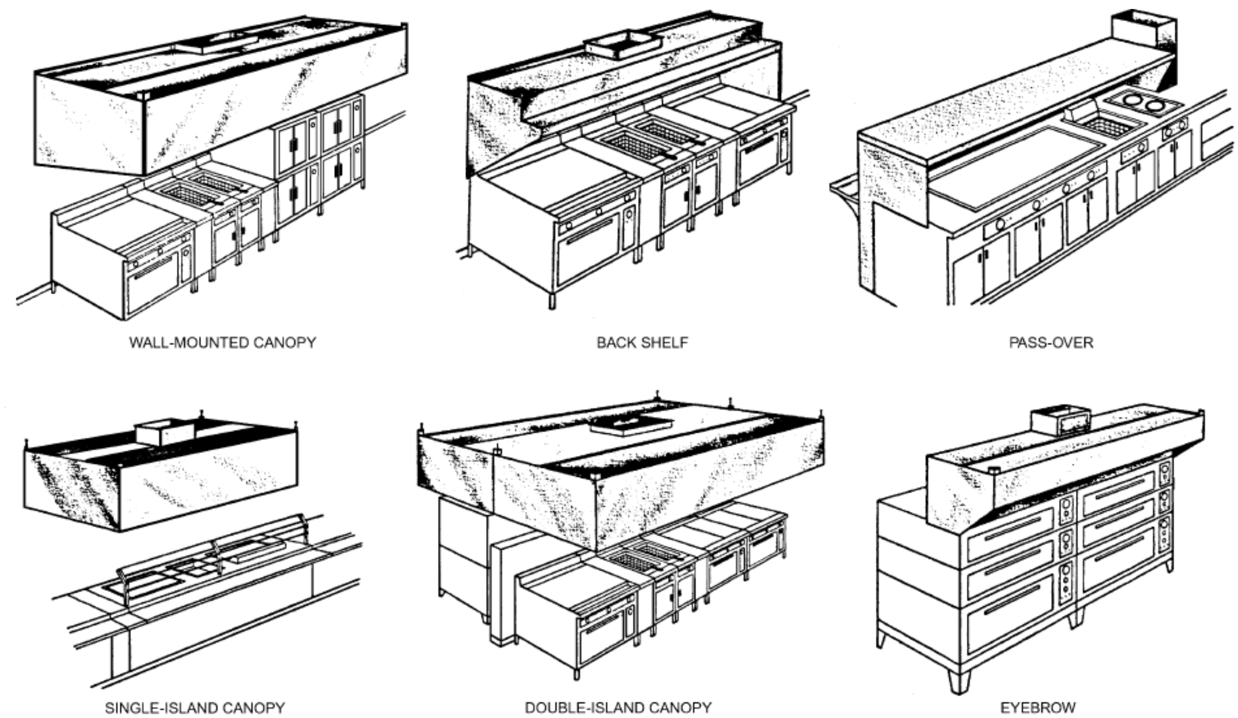


Figure 13. Styles of Commercial Kitchen Exhaust Hoods

A more general design problem for exhaust hoods is the source of replacement air. All air that goes through the hood must be replaced, and if no provisions are made significant negative pressures will be induced, affecting the balance of the HVAC system and drastically lowering efficiency. Replacement air is generally separated into three categories (ASHRAE Handbook, 2007). The first is supply air, where air conditioned to space set point is allowed to be exhausted through the hood. This option is usually the most comfortable for employees, but comes at a significant energy cost, as all the make-up air must be conditioned. The second option is the use make-up air, where outside air is introduced through a dedicated system to the hood. This air is only heated or cooled in extreme conditions, and even then usually not to the same degree as the supply air. Thirdly, transfer air may be used. This is conditioned air from the space adjacent to the kitchen. Transfer air is an efficient source of replacement air because it conditions and ventilates the adjacent space while it provides makeup air for the hood.

How and where this replacement air is introduced into the system also has a complicated but important impact on hood performance. The distribution system to the vicinity of the hood must be designed to prevent high velocities, eddies, or stray currents that degrade the hoods performance by interrupting the natural vertical movement of the plume. Air must be delivered to the hood at a low velocity and uniformly from all directions to minimize the cross-currents that cause spillage from the hood.

The nature of the cooking effluent that must be exhausted is such that duct the duct must be designed specifically for the application. Although standard volumetric rates and pressure drop calculations still apply, there are certain guidelines that must be followed for safety. To be effective, the ductwork must be grease-tight, clear of combustible material, and sized to handle the volume of airflow necessary to remove the effluent (ASHRAE Handbook 2007). Ducts handling flammable cooking effluent are subject to specific building codes, such as those set by the National Fire Protection Association.

The ducting itself should be sloped downward towards the hood or an approved reservoir, so that and grease can drain as it condenses. This ducting should be free from unintentional grease traps, such as bends. In the event of a fire, these traps would act as additional fuel sources to feed the blaze. NFPA *Standard* 96 specifies that the minimum allowable duct velocity is 500fpm. There is no set maximum, but because of noise and pressure drop considerations velocities do not typically exceed 2500fpm. Most ducts are designed with a velocity between 1500 and 1800fpm. UL-Listed modular duct systems typically include double-wall stainless steel construction as well as insulation, which reduces the usual 18" of required clearance from flammable material around the duct. The majority UL- listed systems allow zero clearance to combustibles and have a 2 hour fire resistance rating.

Exhaust fans for kitchen effluent must be designed to handle hot, grease-saturated air. The fan should keep the motor out of the airstream, provide adequate cooling, and should be capable of containing and draining all grease removed from the exhaust. Fans are typically placed at the termination of the exhaust ducting, although in-line fans are available for special applications. The most common exhaust fans, Power Roof Ventilators (PRV's) and centrifugal fans are shown in Figure 14. In most kitchen designs, the exhaust terminations are located on the roof. This provides access to the fans, and directs discharge away from the building. Outside wall terminations are less common, but are still used when roof terminations are not feasible. Care must be taken to insure that re-entry of discharge air into the fresh-air intakes is minimized. This requires providing adequate separation between the exhaust and the intake, which is sometimes specified by code. For stationary establishments, the direction of prevailing winds should also be taken into consideration.

Another option for kitchen ventilation is the recirculating hood, also known as a ductless hood. These hoods are designed to remove grease, smoke, and odor and then return the treated exhaust air directly back into the space.

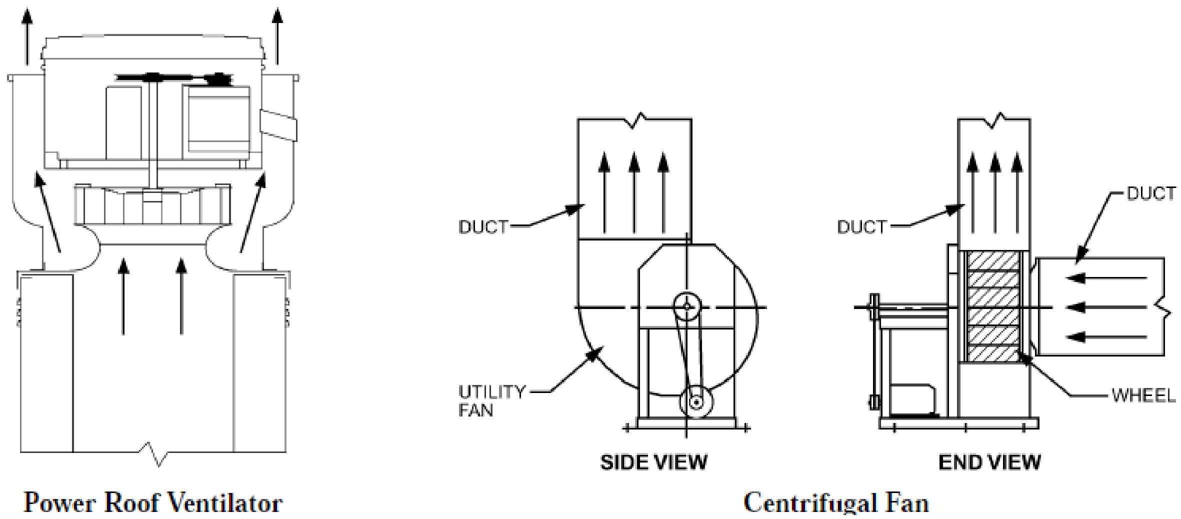


Figure 14. Common Types of Kitchen Exhaust Fans

These hoods do not remove any of the heat load from the thermal plume, so the excess load they impose on the HVAC system as a whole must be considered. To treat the cooking effluent, recirculating hoods contain a grease removal device, a high-efficiency particulate air (HEPA) filter or an electrostatic precipitator (ESP), and some means of odor control such as activated charcoal, and an exhaust fan (ASHRAE Handbook 2007). The NFPA *Standard* 96, Chapter 13 deals exclusively with recirculating hoods, and provides more detailed information on their design and operation.

2.5 Common Kitchen Design Errors

There are many places where errors can occur when designing a kitchen. These errors are usually related to size or space, layout, equipment, and a few miscellaneous problems. Some of these errors are similar, however, it is still very important to consider each error to avoid future problems. Not all errors can be eliminated due to certain restraints, but as many as possible should be eliminated. A kitchen designed with the smallest amount of errors possible, will be able to function smoothly with minimum problems. Below are explanations and solutions to many common errors found in a kitchen.

2.5.1 Overemphasizing One Function

The space allotment should be balanced for all activities so the kitchen can function as efficiently as possible. In most kitchens, the cooking area is often the highlight of the plan and takes priority over all the other functions (Frable, 2). Areas for preparation, washing, and serving become undersized and suffer as a result of under-consideration. To avoid these problems, it is recommended to use space allocation formulas during the design process to reassure enough area is assigned to each function. The space allocation formula can be calculated by summing the area needed for equipment, area of working space, and area of the aisle. By balancing the space, the kitchen will function efficiently and avoid crowding issues.

2.5.2 Undersized Bulk Storage Areas

During the kitchen design process storage areas are usually overlooked. Most of the effort goes into planning the cooking and preparation process, and any space leftover becomes storage space. Many times, this results in a kitchen where the cooking capacity is much larger than the quantity of raw food stored (Frable, 2). This can cause a shortage of food and halt cooking production until the next delivery. If this were to happen, the kitchen could potentially lose a lump sum of money due to the inability to produce food and the sales lost. Storeroom space is based on the net cubic feet required including space for the food, air circulation, and aisle space. The volume needed can be calculated from multiplying the average number of meals served by portion size by time between deliveries. Then add in the volume needed for circulation and aisles. Doing these calculations will ensure ample space for food storage.

Equation for calculating storage volume

Volume needed = (# of meals served) x (portion size) x (time between deliveries) + (aisle & circulation volume)

2.5.3 Poor Space Utilization

Kitchen plans usually reflect what occurs only on the working surface, which is commonly 36 inches high. In order to maximize efficiency and eliminate costly space because size is of concern, it is important to use every lineal foot of space available (Frable, 3). The space can be divided into three levels: wall space, counter space, and space below the working surface. To take advantage of the three levels of space, it is essential to utilize three dimensional drawings and floor plans, as well as equipment elevations. Good examples of equipment elevations would be a double-stacked oven and a wall mounted microwave. Both items will conserve counter space while utilizing wall space. By utilizing such space, it is possible to produce at a capacity of a larger kitchen in a smaller space.

2.5.4 Lack of Vision

Most kitchens do not take advantage of new equipment. Technology changes rather fast and it is hard to predict future technology; however, new kitchens should capitalize on the most recent equipment. In order to do so, a large amount of time should be invested into research on innovative equipment and current technological developments (Frable, 3). Such information can be found through research journals, trade shows, sales representatives and even visits to other newly constructed kitchens. This is a vital part to the design process for several reasons. The main reason is the investment in innovative equipment will ensure that the kitchen is capable of competing with similar industries. Other reasons include efficiency, increased work capacity, energy savings, and less harm to the environment.

2.5.5 Inadequate Clearances for Equipment

There are two types of clearances that need be accounted for. The first type is service clearance. Adequate space must be provided for a repairperson to have enough room to access all parts of the equipment. If enough service clearance is not provided, then it will greatly delay repair time, and ultimately delay food production. To avoid this from happening, provide enough space in the aisle so the equipment can be pulled out or have multiple points of entry to the equipment (front, back, sides, top, and bottom). By doing so, a major crisis will be averted and repairs will be a great deal easier. The second type is clearance between appliances. Equipment failure is often contributed to lack of ventilation and positioning near other equipment that generates high temperatures and greasy vapors. Proper space is vital to prevent this type of equipment malfunction (Frable, 3). Ample room must be left for a ventilation system so the appliance can dissipate greasy vapors and heat away from other appliance. There must also be sufficient space between one piece of equipment to the next. This will help to prevent overheating and other related equipment failure. Proper clearance for a ventilation hood above a stove is shown in Figure 15. Different appliances have varying clearances, so it is very vital to research the required clearance for each appliance. Checking clearances during the design, installation, and start-up phase is an excellent way to make sure proper clearances were utilized. If proper clearances are used, the kitchen should experience a reduced amount of equipment and speedy repair in the case of a failure. It is vital to keep the kitchen running smoothly because wasted time spent on equipment breakdown and repair leads to reduced profit.

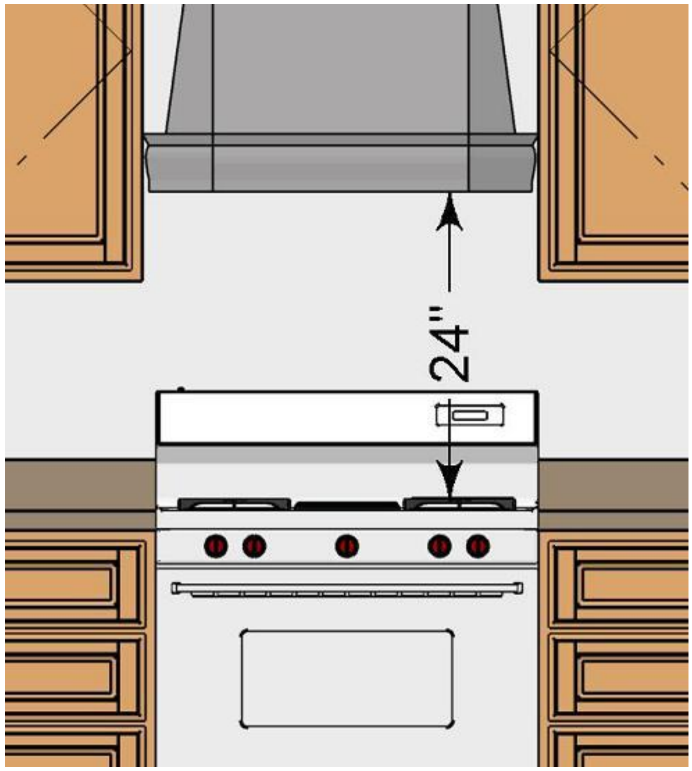


Figure 15. Clearance Space Above a Kitchen Range

2.5.6 Selection of the Wrong Equipment for the Intended Task

For a kitchen, there is a broad amount of different types of equipment and equipment sizes available. Choosing the wrong equipment type or size may have an effect on the kitchens ability to produce the volume required during busy times (Frable, 4). The equipment type and sizes chosen should be able to accommodate multiple demands so the kitchen can process several orders at once to increase efficiency and speed. Sizes should also not be chosen based on available space, but rather the design should reflect ample space for the necessary equipment. It is also recommended to include the chef or operators in the design process. The chef or operator should have an estimate based on the menu of how much volume needs to be produced within a certain time period. This will help the designers pick the equipment according to the required needs of producing at capacity.

2.5.7 No Provisions for Trash

Many parts of the kitchen, especially the food prep and cooking areas, produce hefty amounts of trash and tainted cooking items. Since space is very vital in a kitchen, often times there are no designated space for trash containers on the design plans. What usually happens is trash containers block the aisles or work areas, increasing the difficulty of movement within the kitchen. Spaces for trash disposal should be included on the floor plans as a part of each work area. This will regulate the number and size of trash containers needed. Ensuring enough places to dispose of trash will have a positive impact in the working area. It will add ease to the disposal process so soiled items are not left around the kitchen. This will have an overall effect on the cleanliness of the kitchen as this is far more sanitary. Figure 16 is an example of how to incorporate trash receptacles in the work space while minimizing space requirements.

Figure 16. Under-Counter Trash Receptacles

2.5.8 Inadequate Condiment Storage

In many kitchens, these items are frequently left on counter tops or placed in tubs of room temperature water, when in fact, they should be refrigerated. This usually occurs due to a lack of equipment that will keep the condiments, sauces, and toppings refrigerated while still keeping them readily available (Frable, 4). Health codes mandate that items like these be properly chilled at all times. Most kitchen designs haven't changed in the past 30 years, which can account for one of the reasons the equipment to chill such items are not included in designs. The simplest fix to this error is to leave enough room at preparation and cooking areas for a mini refrigerator. This will keep condiments, sauces, and toppings chilled while allowing quick and easy access that meets health requirements.

2.5.9 Inadequate Space for Supplies

A kitchen should have enough storage space for dishes, silverware, takeout containers, and other necessary items. The storage space should be large enough to hold the proper amount of such items to meet the demands of production (Frable, 4). It is recommended to have a slightly larger space than necessary for storage of these products to reduce the risk of not having enough during peak periods of production. These items should also be stored in an easy to reach place to make access to them as quick as possible. The cooking area, preparation area, and service window is where the bulk of the storage should take place. Those areas require the most use of dishes, silverware, containers, and paper supplies. This is another thing the designer should keep in mind when creating floor plans and allotting space to make the kitchen as balanced as possible.

2.5.10 Lack of Landing Areas and Workspace Next to Equipment

It is common to find in some kitchens that there is not enough space to work or place needed items next to equipment that is being utilized. Workspace is an area mostly where preparation is being done and landing areas are places where items, like pots and pans, can be put on (Frable, 5). Workspace and landing areas are most commonly needed at stoves, ovens, fryers, and refrigerators. The designer should include enough room for both workspace and landing area next to each vital piece of equipment that will be utilized often. These areas can be very valuable. They allow hot dishes to be placed right next to the equipment. This reduces the risk of injuries and burns to the workers, as these hot dishes will not have to be carried long distances. Second, sufficient work space will prevent crowding around a small single work place, which will increase comfort and efficiency of the workers. Examples of useful landing spaces for an oven and stove are shown in Figures 17 and 18.

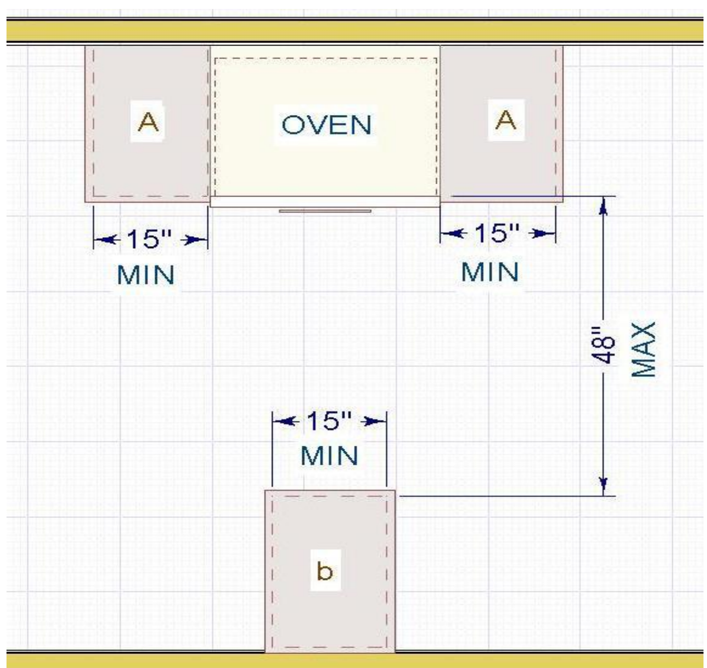


Figure 17. Minimum Dimensions for Oven Landing Areas

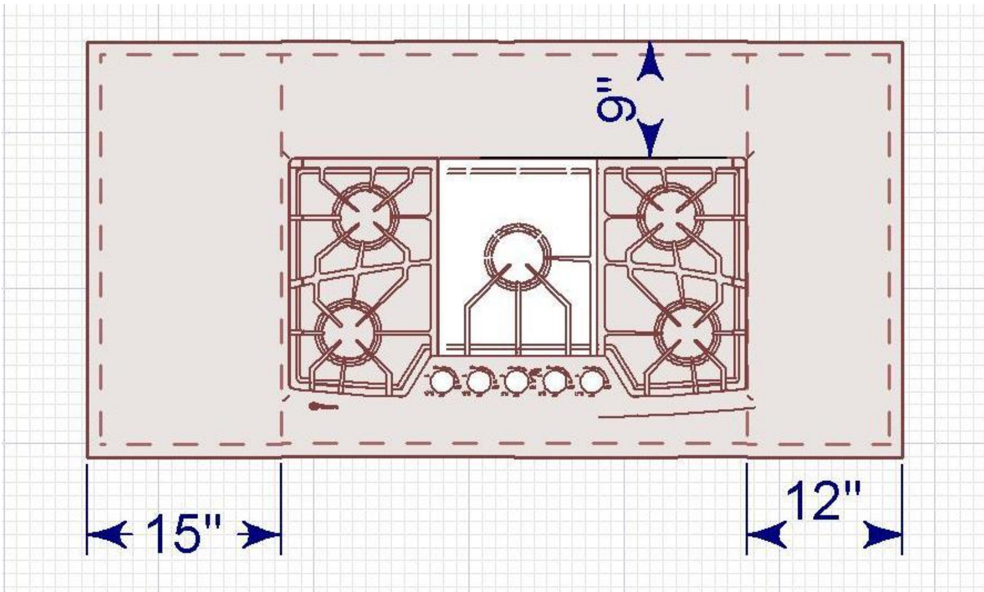


Figure 18. Suggested Landing Areas for a Stove

2.5.11 No provision of necessary swing clearances

Full arc swings of all oven and refrigerator doors should be measured and included in the layout of the kitchen before installation to ensure all doors can fully open. Also, it is extremely helpful if refrigerator and warmer doors swing so they open towards the intended work area next to the equipment. Adjustments to the arrangement of the equipment must be made if the previous two provisions are not met (Frable, 5). Purchasing refrigerators and warmers with field reversible doors will make it easier for doors to open towards the work area. Ordering and shipping errors also occur, so door arc swings and door location should be double checked upon arrival of equipment to make sure the current plans are still accurate. Failure to leave proper clearances of door swings or drawers will result in the inability of the equipment to fully open. This can cause massive problems as refrigerators, ovens, or drawers will be difficult to access or not accessible at all. Failure of proper swing clearance is shown in Figure 19.

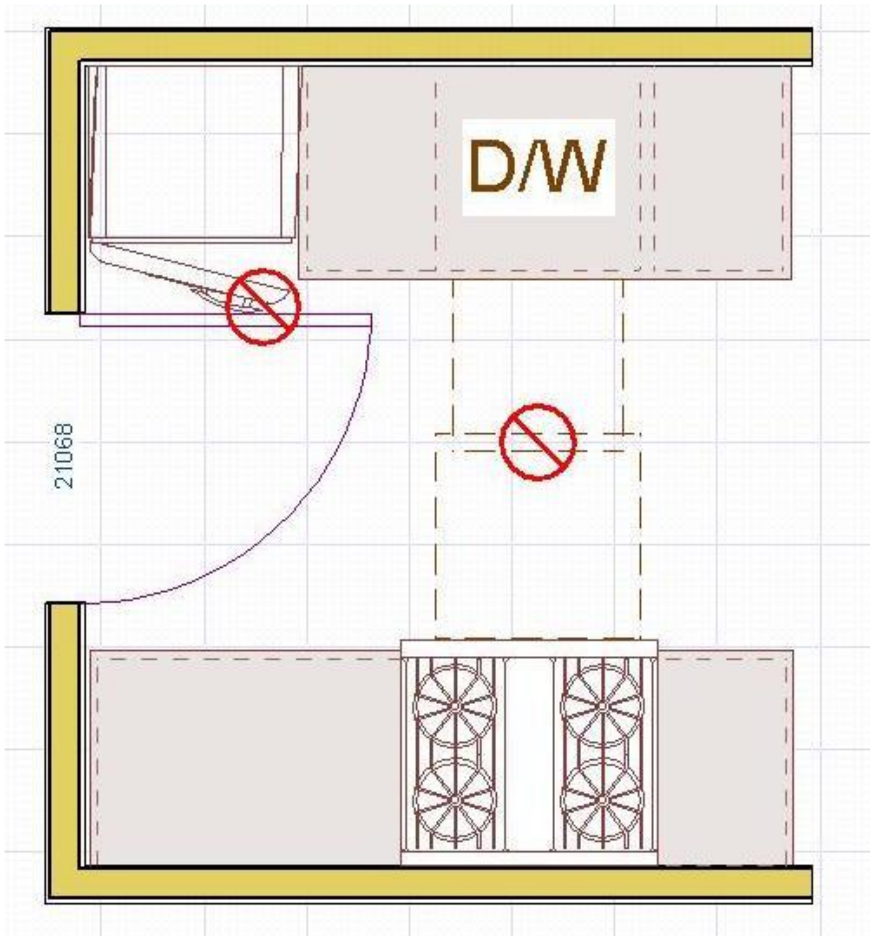


Figure 19. Example of improper swing clearance

2.5.12 Doors that Swing Into Main Traffic Aisles

This problem cannot be completely avoided, but as many provisions as possible should be made to limit the amount of doors that swing into aisles. Many kitchen accidents are caused by this as employees do not notice the opened doors and stumble into them (Frable, 6). Also, doors that block the aisle increase the difficulty of movement in an already crowded kitchen. Production can be slowed during busy periods if doors block the aisles. The biggest problem with this occurs on the large cooler doors that almost completely block the aisle. A few solutions to this problem include sliding doors, offsetting door panels, and doors that open into the cooler.

It will also help if large doors are located in parts of the aisle where traffic is light, like the ends of aisles.

2.5.13 No Space for Bread and Rolls

As mentioned previously, kitchens should be evenly balanced so all functions can be fulfilled. Often times, kitchens do not have sufficient space for their bread needs (Frable, 6). A large amount of space is needed to sustain the wide variety of breads that are necessary in a kitchen. Bread and rolls should be enclosed in drawers or cabinets that are within easy reach of work areas and protected from contamination. Required volume for bread can be determined by the quantity of items on the menu that use bread. It is vital that a kitchen has enough space for bread to prevent shortages during peak periods.

2.5.14 Unprepared for Changes in Design

There are many unpredictable factors that can occur between the design phase and completion of installation that can cause the kitchen layout to change. Such changes can occur in the menu, equipment, space, clearances, and numerous other possibilities (Frable, 7). In order to keep things running smoothly, contingency funds and alternative plans should be set up at the beginning. This will ensure proper funds for unforeseen costs and substitute use of space if the layout changes.

2.5.15 Lack of Coordination and Communication

To prevent unexpected columns interfering with equipment or beams running through exhaust hoods and cabinets, it is important that the kitchen planners, architects, and engineers synchronize their work (Frable, 8). Without consulting each other, they tend to make assumptions about the project that can severely affect the overall plans of the project. If there is a lack of coordination during the design process, then many inconsistencies will appear during the construction process. This will not only stall the construction process, but will result in a less than optimal kitchen than originally planned.

2.5.16 Too Much Emphasis on Reducing the Budget

It is important when designing a kitchen to balance production and storage requirements with existing budget. Sometimes if funds are limited, some kitchens decide to make cost cuts that are detrimental to the kitchens function (Frable, 7). Such decisions will hurt the kitchens production, efficiency, and profitability. To reduce costs without hurting the kitchen's function, make balanced reductions in all areas of the kitchen. This will cut costs as the kitchen is downsized and the kitchen can still function properly as all necessary parts are still included. Not making balanced reductions can result in overemphasis in one area and lack of ability in another, which will hurt the kitchen's production.

2.5.17 Too Many Cost Cuts on the Infrastructure

Often times, kitchens downgrade their coolers, ventilators, exhaust fans, and other major equipment to save money. However, these are vital pieces of a kitchen that need to be able to function properly for as long as possible (Frable, 9). Downgrading the equipment can lead to reduced functionality of the kitchen and the equipment has a greater chance of needing to be replaced in the future. Replacing equipment in an already operating kitchen will only increase costs and stop production for a while. If cost is a concern, it is recommended to lease expensive items and use quality equipment with lower-cost finishes. This way, the equipment is still of good quality to meet production demands and money is saved.

2.5.18 Location of Open Flames Next to Fryers

Codes mandate that a separation between open flame cooking and deep-fryer equipment is necessary. A stainless steel shield is also permitted as part of the code to separate the two pieces of equipment (Frable, 9). However, the shield is usually a problem as it is a barrier that can interfere with workflow. The best solution to this problem is to place a griddle or flat-top range next to the fryers. This way there are no open flames and the work line is maintained without any barriers. Not distancing open flames and fryers can lead to serious grease fryers, which can cause many problems.

2.5.19 Failure to Include Necessary Sinks

It is necessary to have proper provisions for sanitation in a kitchen to meet local health department codes. In many kitchens, hand sinks and mop sinks are forgotten. However, where hands are washed and where mop buckets are dumped should be separated from where dishes are washed (Frable, 10). This provision will improve sanitation in all kitchens and help meet health codes. Other proper sanitations methods are listed in other sections of this chapter.

2.6 Sanitation

The safety of mobile food preparation, such as that sold by street vendors, is concerning because of the limited or poor facilities of the units and carts, the poor food handling practices of the vendors, and the potentially hazardous foods that are sold. Numerous studies have documented the common sanitation violations of mobile vendors, among them inadequate cooking and holding temperatures, little or no hand washing, poor ware washing facilities, and insect and vermin contamination, cross-contamination, and lengthy temperature abuse of foods (Schmidt and Rodrick, 557). All authors concurred that contamination of mobile vendor's wares represented a serious potential risk for consumers.

In a 1998 investigation by Donna St. George of The New York Times, a random sampling of chicken, burgers and kebabs from vendors' carts showed significant undercooking in 39 of 51 cases, or more than 75% of all food tested. Dr. Robert Gravani, a food scientist at Cornell University, was invited to partake in the Times' investigation, and found violations of sanitary food handling protocol to be both numerous and grievous. Vendors would frequently leave both cooked and uncooked food at ambient temperature, which is deal for the growth of many strains of bacteria, such as *E. coli* and *Salmonella*. Of the 254 vendors observed for 20 minutes or more, not a single one was seen washing their hands. In Chinatown, one a street vendor was observed using his bare hands to slice and scoop raw pork and duck, wiping his hand on rag, counting money, and preparing meat again, without any hand washing in between. Furthermore, in a survey of over 400 New York residents, 1 in 10 said they had become ill after eating at a mobile food cart.

One state health official in Olympia, Wash remarked on the typical food cart conditions: "If you don't have refrigeration and temperature control and you don't have hand washing," he said, "you're asking for an outbreak."

2.6.1 Types of Contamination

There are three main types of potential food contaminants: physical, chemical and biological. Also referred to as food safety hazards, these contaminants can be transferred to the food at any time during the production sequence, from harvesting to serving. Developing an understanding of these contaminants and how they behave is key in designing a kitchen to prevent and interrupt hazardous food contamination.

Biological hazards include bacterial, viral, and parasitic microorganisms. These pathogenic microorganisms of various types represent the largest source of contamination, and are by far the most frequent cause of food-borne illnesses (Lelieveld, 66). Even when these microorganisms are destroyed by heating, they may have previously produced toxins which makes preventing the initial contamination that much more vital. Similarly, the spores of spore-forming bacteria such as *Bacillus Cereus*, *Clostridium botulinum*, and *Clostridium perfringens* survive cooking and may germinate and grow if food is not properly cooled or held after cooking (Food Code 2009, Annex 4).

Viral contamination is also frequent and most illnesses are caused by of norovirus, hepatitis A, and rotavirus. The presence of these viruses is usually directly related to contamination from human feces, most likely due to poor hand washing practices. Unlike bacteria, cooking as a control for viruses can be ineffective, as many foodborne viruses exhibit heat resistance at the recommended times and temperatures of cooking (Food Code 2009, Annex 4). This makes preventing initial contamination all the more vital in preventing foodborne illnesses due to viruses.

Several simplified models for microbiological contamination of food have been proposed. The simplest is the “chain of infection”, which is a series of related events and conditions that must occur or be met before an infection will occur (Gravani, 2). The “links” in this chain are *agent*, *source*, *mode of transmission*, and *host*. To prevent food contamination the chain of infection must be broken. The total eradication of infectious agents is generally not feasible, so emphasis is placed on the remaining three links of the chain. The three primary ways to avoid the occurrence of food-borne illnesses are: removing the source or reservoir for each agent, preventing transmission of the agent from the source to a food, and retarding growth the microorganism in the food or host that has been contaminated (Gravani, 34).

Physical and chemical contamination is less common than contamination by pathogenic microorganisms, yet they are still important factors to consider. Physical contaminants found in a typical kitchen environment are numerous and include glass, metal and plastic fragments from surfaces and equipment, dirt, rust, hair, jewelry, etc. These physical contaminants compromise food safety in numerous ways, exposing consumers to the risk of cuts, choking, broken teeth, and infection. Therefore, a well designed kitchen must minimize the likelihood of the introduction of these foreign objects.

Large amounts of chemicals present in kitchen environments, including lubricants, sanitizers and cleaning products and pesticides. Improper use and storage of these chemicals can potentially expose food products and cause contamination. To ensure food safety, it is important that chemical use within the kitchen environment is minimized and monitored, and that all chemicals are stored in well sealed containers and separate from foodstuff. These chemicals should be well labeled and a Material Safety Data Sheets (MSDS) should be provided.

Even chemicals specially designed for foodservice use, such as sanitizers, can be dangerous in high enough concentrations. Although the use of dilute sanitizer solutions is not hazardous, placement of containers of concentrated sanitizers on or above food equipment has the potential to expose consumers to toxic chemicals (Schmidt and Rodrick, 480). It is therefore important to treat concentrated sanitizers as potentially hazardous and use them in low concentrations not exceeding those recommended by the manufacturer.

Although not technically contaminants, familiarity with common food allergens is a part of safe food handling. It is estimated that over 11 million Americans suffer from one or more food allergies (Food Code 2009, Annex 4). A food allergy is caused by naturally-occurring protein within foods and can cause anaphylactic shock and death in severe cases. The most common allergens, which account for over 90% or more of all food allergies, are: milk, eggs, soy, fish, shellfish, tree nuts, wheat and peanuts. To prevent severe allergic reactions, information on common allergens with in the food being served should be posted in plain view, and complete information on all ingredients should be available on request.

2.6.2 Sources of Contamination

Employees – The largest and most dynamic source of potential food contamination in a kitchen environment is the employee's themselves (Gravani, 80). This is because employees are both a source of microbiological contamination, and frequently come into close contact with the food during preparation. Therefore, if an employee does not practice good personal hygiene and proper sanitary procedures, they can contaminate food with harmful microorganisms or physical and chemical taints. Within an individual employee there are numerous sources of contamination such as the hands, mouth, scalp, etc. These sources are covered in more detail on the section on employee hygiene and behavior.

Equipment Surfaces –Equipment surfaces can be contaminated through many different means, including the settling of microorganisms and other debris from the air, as well as from employees and food products. In particular, cross-contamination by kitchen surfaces is a large concern. Poor food handling behavior by employees coupled with difficult to sanitize surfaces can cause cross-contamination, where harmful bacteria are transferred from a surface or utensil to the product. Product contamination by equipment surfaces can be reduced by improved design and more effective cleaning procedures.

Air and Water – Throughout the preparation process food is continuously exposed to air and water, during washing, rinsing, or simple exposure to the atmosphere. Each of these exposures has the potential to contaminate the food if the air or water contains unacceptable levels of microorganisms or chemicals. The pathways for contamination by water are numerous, and include steam or water vapor, condensation, leaking pipes or drains, cleaning and rinsing, and rainwater. Stagnant water is particularly hazardous, because under favorable conditions microbial levels can quickly become dangerously high (Lelieveld et. al, 62). For these reasons, it is vital that water of high quality be used for all operations.

The air can be a vector for contamination by light foreign bodies, like dust and insects. Chemical contamination through the air can also be a problem. With this in mind, proper design and implementation of kitchen ventilation can directly help reduce food contamination and improve overall quality.

Waste and Sewage – The food preparation industry generates large amounts of waste products such as used packaging materials, unused foodstuffs, and sewage. A properly designed kitchen must include features to isolate and remove this waste while avoiding exposure to preparation surfaces, equipment and product. For the disposal of refuse receptacles should be conveniently located in work areas to accommodate waste. Gravani provides a detailed description of the proper design of trash receptacles:

> "[They] should be seamless, with close-fitting lids that should be kept closed except when the receptacles are being filled and emptied. Plastic liners are inexpensive and provide added protection. All receptacles should be washed and disinfected regularly and frequently, usually daily. Containers in food processing and food preparation areas should not be used for garbage or litter."

As with other equipment for food processing areas, emphasis should be placed on ease of cleaning. Receptacles, specifically, must be convenient to use so that employees use them in a consistent and proper manor.

Insects and Rodents, etc. – Pests and other vermin are highly mobile reservoirs of contamination and agents of transmission. To prevent transmission of contamination, total eradication is necessary and all food processing, preparation, and serving areas should be designed to prevent entry of pests (Gravani, ch5, pg6). Proper disposal of solid waste in sanitary storage facilities and quick cleanup of spills is also important to avoid attracting pests (Schmidt and Rodrick, 465). In urban environments, birds such as pidgins can be both a nuisance and a health hazard. Therefore either the exterior of food service structures should be designed to prevent them from landing and roosting, or other types of repellents should be used (Schmidt and Rodrick, 465). These other forms of repellents should be analyzed carefully to ensure they are not a contamination hazard.

Other Sources of Contamination - It is also important to consider non-product contact surfaces, such as floors, walls, ceilings and supports. As well as being reservoirs of microbial contamination, they can also be a source of physical and chemical contamination (Lelieveld, 51). For example plaster from ceiling tiles can contaminate food and surfaces with chemical residues and physicals chips. Therefore, these auxiliary surfaces must to be designed so that they are durable and can be effectively cleaned.

The packaging that is designed to protect food can also represents another possible a source of contamination. When bulk food products are shipped on pallets they are exposed to foreign contaminates such as nails, staples and wooden fragments from pallets that have the possibility to work their way into dry goods. Bottles and cans are also susceptible to chipping and denting, respectively (Schmidt and Rodrick, 465). To prevent contaminated food from posing a hazard, all incoming shipments should be carefully inspected for damage. In the case of cans, and misshapen, dented or swollen cans should be rejected (Schmidt and Rodrick, 465).

2.6.3 Sanitary Employee Behavior

Employees represent the single largest source of contamination within the food industry. In fact, it is estimated that employee based factors contribute to upwards of 90% of foodborne illnesses in food service establishments and in the home (Griffith, from Blackburnm 90). Therefore, the single most important means of reducing the occurrence of foodborne illnesses lies in improving employee behavior and hygiene.

An employee can compromise food safety through two closely related means. The first of these is through poor personal hygiene. Even a clean human body is a huge source for infectious microbes and physical contaminants, and this is exacerbated when an employee does not have good hygiene. The second way an employee can compromise food safety is through improper food handling practices and unsanitary or negligent behavior. Through their actions, employees can both spread contaminants from themselves and other sources, and allow already present biological contaminates to reach dangerous levels.

At times it can be difficult to separate the influences of hygiene from poor food handling practice of unsanitary behavior, as the two have a large impact on each other and are not mutually exclusive. The exact cause of illnesses caused by food service employees can be difficult to determine, and often both poor hygiene and food handling practices are to blame, as they are dependent on one another. For instance, it is almost impossible for an employee with bad personal hygiene to handle food in a safe manor, and even employees with great hygiene can contaminate food through improper handling. Therefore, it is important to remember that although personal hygiene and food handling behavior will be discussed separately for purposes of clarity and organization, the methods described for educating employees on proper behaviors and preventing unwanted behaviors are valid for both.

2.6.4 Personal Hygiene

Personal hygiene is a measure of the cleanliness of one's body and maintaining good personal hygiene is the foremost tool in preventing food contamination by employees. It has been estimated that poor employee hygiene is a contributing cause in 35% of cases of foodborne illnesses (Schmidt and Rodrick, 537). It is therefore crucial to develop an understanding of exactly what constitutes hygienic employee behavior and how this can be achieved.

There are many facets of personal hygiene, which Gravani breaks down into the following categories: skin and hair, fingers and fingernails, respiratory system, eyes, and digestive system. Each of these represents a possible source of contamination if not properly maintained.

The skin is the largest organ in the human body and represents a very large source for contamination. Skin is made up of two primary layers, the outer epidermis and the inner dermis.

When dead skin cells from the epidermis mix with perspiration and oil secreted by the glands of the dermis it forms an ideal environment for bacterial growth (Gravani, 34). If food handlers rub or scratch their skin, bacteria may be transferred from their hands onto the food.
Excessive perspiration on the skin can drip onto prepared food, further stressing the need for adequate temperature and environmental control.

The skin also represents a source for *Staphylococcus aureus* and *Staphylococcus epidermis*, which are the skins dominant bacterial species and can cause foodborne illness (Gravani, 54). These staphylococci bacteria and other microorganisms are also found in the hair follicles of the scalp. The use of hairnets can prevent transmission of staphylococci bacteria found on the scalp, and well as reduce the unappetizing incidence of finding hairs in food. For more general prevention of food contamination by skin and hair, employees should be required to bath frequently and wear clean clothes when in proximity to food.

The hands are particularly important because they are often contaminated with bacteria, due to the high frequency of which they come in contact with sources. These sources of bacteria are numerous and include dirty equipment, contaminated food, clothing, and other areas of the body such as the eyes or mouth (Gravani, 123). The hands then come in close contact with the product, transferring the previously picked up bacteria.

Hands can also be a source of physical contaminates, and therefore the FDA Food Code § 2-303.11 prohibits employees from wearing jewelry (other than a plain ring such as a wedding band) while preparing food and also mandates that fingernails remain short and trimmed. This is also because jewelry and long nails can reduce the effectiveness of hand washing.

To prevent contamination by the hands, a strict procedure of hand washing must be followed. Hand washing effectively reduces the level of microorganisms present by ten to 100 fold (Gravani, 17), and has been described by the CDC as the most important means of preventing the transmission of communicable disease.

For a hand washing program to be effective several components must be taken into consideration:

Design and Location– For a hand washing sink to be effective it must be placed in a location that makes it easy and convenient to use. These sinks must be specific for hand washing and separate from preparation or three compartment dish-washing sinks, which are not accepted by regulatory agencies for the use of hand washing because of the possibility of contamination (Schmidt and Rodrick, 480). Hand washing sinks should have a water supply temperature of 100 to 115ºF, and a flow rate of 2 gallons per minute (Schmidt and Rodrick, 480). The use of automated technology such as sensor activated sinks and soap dispensers is encouraged because it minimizes contact with surfaces that could possibly cause recontamination. Sensors can also be used to track sink usage and provide data on frequently employees are washing their hands.

For drying hands, both paper towel dispensers and air dryers of various types are acceptable. However, automatic, continuous-feed paper towels are preferred because the friction generated between the hand and the towel during drying further reduces levels of bacteria (Schmidt and Rodrick, 480).

Hand Washing Procedure – There are numerous regulatory agencies that have published guidelines for hand washing procedure. A common feature to almost all is the focus placed on cleaning the finger tips. This is because dirt and fecal pathogens tend to be build up on fingertips, especially in the fingernail and cuticle area. These high concentrations of infectious bacteria and viruses found around the fingernails can easily cause contamination the product during preparation. (Gravani, 23). Hence, particular attention must be paid to cleaning under and removing all traces of grime from the fingernails when washing hands.

The FDA Food Code § 2-301.2 specifies a specific procedure for hand washing that Food employees must use in the order stated to clean their hands and exposed portions of their arms:

(1) Rinse under clean, running warm water;
(2) Apply an amount of cleaning compound recommended by the cleaning compound manufacturer;
(3) Rub together vigorously for at least 10 to 15 seconds while:
  (a) Paying particular attention to removing soil from underneath the fingernails during the cleaning procedure,
  (b) Creating friction on the surfaces of the hands and arms or surrogate prosthetic devices for hands and arms, finger tips, and areas between the fingers;
(4) Thoroughly rinse under clean, running warm water;
(5) Immediately follow the cleaning procedure with thorough drying using a method one of the following methods:
  (a) Individual, disposable towels;
  (b) A continuous towel system that supplies the user with a clean towel;
  (c) A heated-air hand drying device;
  (d) A hand drying device that employs an air-knife system that delivers high velocity, pressurized air at ambient temperatures.

Frequency of Hand Washing – In general, hand washing should occur before touching anything that must not be contaminated, such as prepared food or utensils, and after touching any potential source of contamination, such as raw meat, unwashed vegetables or bodily fluids (Schmidt and Rodrick, 480). Due to the high concentrations of infectious microbes and fecal bacteria within the restroom, the potential for exposure is extremely high. Therefore, proper hand washing after use of the restroom cannot be stressed enough.

The specific times when it is mandatory to wash hands according to the FDA's Food Code are listed in Table 4, but there are other times when hand washing is advisable, such as in between glove changes. Requiring employees to wash whenever they return to the kitchen can also be beneficial. Having a sink near the kitchen's entrance makes this convenient to employees and increases the likelihood that such a policy would be followed. In addition, some food service establishments require their employees to wash their hands at set time intervals (Schmidt and Rodrick, 484). However, this can have the unintended consequence of postponing hand washing until the designated time, which increases the potential for the spread of contamination.

Most local jurisdictions and the Federal Food Code do not list "after handling money'' as a necessary time to wash hands, yet money as a substrate has recently been shown to allow survival of pathogenic organisms for several hours (Schmidt and Rodrick, 484). Consumers also view food handing after processing monetary transactions with the hands as unhygienic and unacceptable. Therefore, in our kitchen design we will provide for a designated cashier or a hands-free means to process transactions.

Glove Use – When combined with proper hand washing intervals and procedures, the use of gloves can be very effective. Gloves serve as another barrier between the skin and the products which protects the food from contact with contaminants found on the fingertips. The use of gloves is therefore be mandatory when handling all foods that are ready to eat (RTE) and require no further cooking.

There are a few drawbacks to the use of gloves for food preparation. One danger of glove use is the occlusion of the skin underneath the glove, which creates a favorable environment for bacteria growth and greatly increased bacteria populations. Therefore, hand washing should accompany all glove changes (Schmidt and Rodrick, 480). Glove use can also decrease hand washing and create a false sense of security among employees, causing them to be less careful and touch contaminants without changing gloves afterward. To prevent this, employees must be taught about the correct way to use gloves and monitored for unsafe behavior. Another added benefit of glove use is the positive psychological effect it has on those observing the food being handled.

For our mobile kitchen we intend to make gloves readily available, incorporating convenient locations for dispensers into our design. The dispensers will be located as close to high risk preparation areas (such as raw meat preparation) and hand washing sinks as possible. This will help to insure that gloves are used correctly and serve to further reduce the possibility of foodborne illnesses.

Table 4. When to Wash Hands (Adapted from Food Code 2009 § 2-301.14)

• Before beginning work. • Before handling food. • After touching bare human body parts other than clean hands and clean, exposed portions of arms. • After using the restroom. • after coughing, sneezing, using a handkerchief or disposable tissue, using tobacco, eating, or drinking	• After handling soiled equipment or utensils. • When switching between working with raw food and working with ready-to-eat food. • Before putting on gloves for working with food. • During food preparation often enough to remove contamination.

2.6.5 Proper Food Handling Procedures

The FDA Food Code provides an exhaustive description of what defines popper food handling practices, and should be seen as the go-to guide for those seeking specific information. Here we will provide a general overview as well as important conclusions. The facets of proper food handling will be covered in the order in which they typically occur, rather than by their relative contributions to cases of food-related illnesses.

Storage – All food should be stored in covered containers, or wrapping and at the proper temperature. These containers should allow the product within to be readily and unmistakably recognized. The first-in, first out method of stock rotation should be used to determine the order of stored food utilization, meaning that the food that has been in storage longest is first to be used. . To do this, food must be properly labeled with the date it was placed into storage. Products must not be stored for too long, and should be disposed of if stored for periods longer than allowed in the Food Code. The Food Code also list proper temperatures for refrigeration and freezing, which are below 41°F and 0°F, respectively. To insure food remains at the recommended temperature during storage, our kitchen's cold storage units will have temperature monitoring and alarm capability.

The height of storage should be dependent on the relative hazard the food presents to prevent cross contamination. Specifically, cooked food must be stored above raw foods, with raw animal products occupying the lowest shelf.

Preparation – The two most important food safety considerations during the preparation phase are minimizing cross-contamination and time spent at unsafe temperatures.

Cross-contamination is usually poses during the preparation phase. Lack of adequate cutting boards can cause employees to use the same cutting board or utensils to cut raw meat/poultry/fish and cooked items without sanitizing after each use (Schmidt and Rodrick, 538). It is therefore advisable to have multiple cutting boards, colored to correspond with the foods allowed to be prepared on them. For instance, yellow cutting boards can only be used for pork preparation, and red cutting boards for beef.

Seafood and raw meats of all types are typically received and stored frozen, and it is often necessary to thaw these foods before cooking for culinary considerations such as quality and taste (Schmidt and Rodrick, 474). To prevent the exterior of food from reaching unsafe temperatures, thawing should either be done under refrigeration or under cold running water.

Cooking – The main goal behind the cooking of raw food, aside from taste and aesthetics, is the destruction of organisms that could cause illness. To do this, food must be held at a specified temperature for a specified amount of time; the higher the temperature, the shorter the time a food must be held there. As a general rule, most aw animal foods such as eggs, fish, meat, poultry, and foods containing these can be cooked to a heat of 145^{o}F for a time of 15 seconds. Specific cooking times and temperatures can be found in the 2009 Food Code §3-401 to §3-404. To ensure food has reached these required temperatures necessitates the use of a thermometer.

There are also specific rules for the reheating and cooling of potentially hazardous foods that have been previously cooked. For example, foods must be reheated so that all parts of the food reach a temperature of at least 74^{o}C (165^{o}F) for 15 seconds to ensure the destruction of any microorganisms present. The procedures outlined in the food code for cooling foods are designed to minimize the time that food spends in the temperature range of dangerous bacterial growth, as seen in Fig.20.

Hot Holding – Holding food at elevated temperatures is frequently done in food preparation facilities. The 2009 food code states that food must be held at a minimum of 57^{o}C (135^{o}F) I covered containers. Again, this is to ensure that food does not sit in the temperature danger zone between 41°F and 135°F for long, and to destroy bacteria that may have grown during storage.

Aside from not following proper food handling procedures, there are many unsanitary or negligent behaviors that employees can engage in that compromise food safety by introducing biological, physical and chemical contaminants. For example, if an employee fails to adequately clean and sanitize a food preparation surface, the potential for all three types of contamination exist.

Cross-contamination is also significant because of poor hygienic practices such as wiping hands on aprons or on common cloths, instead of hand washing." (Schmidt and Rodrick, 473)

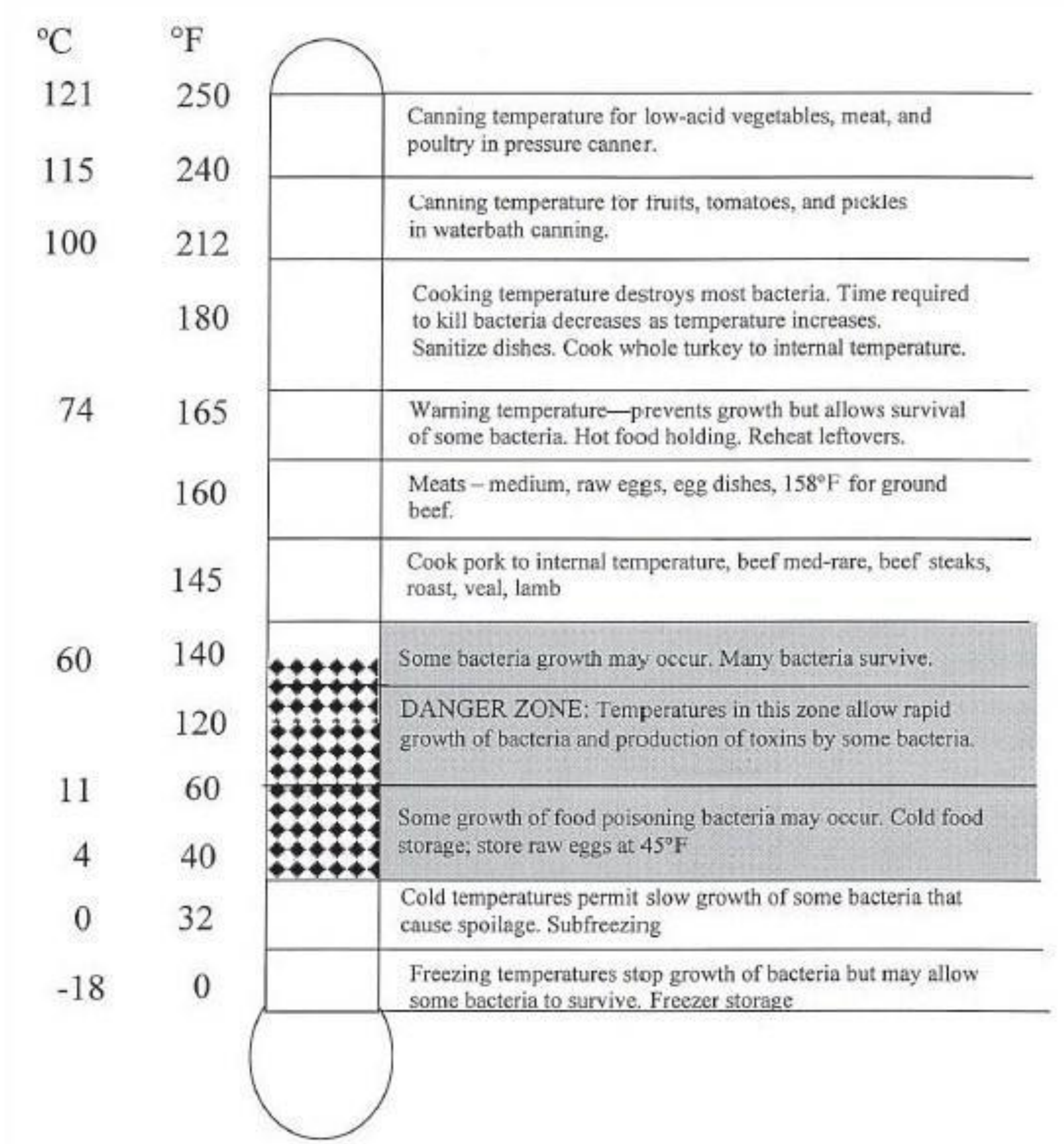


Figure 20. Temperature of Food for Control of Bacteria. From Schmidt and Rodrick

Preventing unwanted behaviors – It is not always ignorance that prevents employees from following proper procedure. In a recent study by done Clayton et. Al of the Food Safety Research Group of the University of Wales, 62% of food handlers admitted to sometimes not carrying out all food safety behaviors on every occasion, with 6% admitting that they neglected to do so on a frequent basis. Further results from the study are outlined in Table 5.

The most common reason cited by employees for violating recommended practice was lack of time, manpower or other resources. The food handlers in the study were also unaware of the high risk involved in preparing food, believing the profession to be very low-risk (Clayton et Al, 20). This study highlights the need for training to be risk-based, making the employee aware of exactly how negligent behavior or errors could put lives at stake. The study also demonstrates that behavioral change will not occur merely as a result of training and that sanitary practices will only be implemented given sufficient resources and the correct management culture.

Other complicating factors in the food service industry are high staff turnover, large numbers of part-time staff, low pay/status, and poorer educational backgrounds (Griffith, 272).

Although classroom and video instruction remains effective, focus is now placed on behavior-based training. In this method, emphasis is placed on correcting behaviors, rather than on changing attitudes and individuals. Positive personal hygiene is rewarded, and negative activities are curbed through management policies and supervisory behavior (Chao, 219). It is also recommended to couple behavior-based training with a system of continuous evaluation to determine the program’s effectiveness and ensure employee competence remains high.

Table 5. Percentage of Employees Practicing Food Safety Behaviors

Specific Food Safety Behavior	Risk Factors	Percentage of Respondents
Wash hands	CC, IFH	84
Clean equipment, utensils and surfaces	CC	66
Prevent cross-contamination	CC	58
Ensure food is cooked thoroughly	IH	57
Maintain good standard of personal hygiene	CC, IFH	53
Do not smoke	CC, IFH	50
Keep food at appropriate temperature	IH, IS	50
Use of color-coded cutting boards	CC	43
Correct stock rotation	IS	40
Label food correctly with dates	IS	34
Wear gloves	CC	33
Cover foods	IH, IS	30
Ensure uniform is clean	CC	28
Correct storage of foods	IS	27
Keep raw and cooked foods separate	CC	25
Use correct/different knives	CC	17
Correct storage of waste	CC	17
Report all illnesses	IFH	12
Make sure employees are trained	CC, IH, IS, IFH	11
Correct storage of chemicals	CC, IS	9

CC, cross-contamination; IH, inadequate heating; IS, incorrect storage; IFH, infected food handler

Adapted from Clayton et Al., *Food handlers' beliefs and self-reported practices*, 2000

2.6.6 Hygienic Design

Construction materials - One of the largest factors in improving hygienic design of equipment and food preparation surfaces is material selection. A concise summation of required material properties is given in “Hygiene and Food Processing, Part II”:

> Product contact materials must meet a number of requirements. They must be inert to the product under operating conditions, including variations in temperature and pressure, as well as to detergents and disinfectants under conditions of use. They must be corrosion resistant, non-toxic, mechanically stable, smooth and cleanable, and such that the surface finish is not adversely affected under conditions of use. Non-product contact materials must also be mechanically stable, smoothly finished and easily cleanable. (Lelieveld et. al, 167)

In addition factors such as cost and ease of manufacture should be included in any real-world analysis. The most common and widely used materials are Austenitic Stainless Steels, such as SAE Grades 304, 316, and 316L for higher temperature or welded applications. All Stainless Steels must be adequately passivity before use. Other metals appropriate for food contact use are nickel or chromium plated metals and enamel coated surfaces. If plating is used, care must be taken to ensure it doesn't flake or otherwise contaminate the product. When plating materials for food service use, it is important to use chemical plating over electroplating. Electroless chemical plating produces a coating with excellent wear and corrosion resistance, due to its highly compact surface layers (Kalpakjian, 1072). It is also acceptable to use materials that offer better corrosion resistance than Stainless steels, such as Hastelloy, but this is cost prohibitive.

Certain polymers and elastomers may also be used, but care must be taken as they could contain leachable toxic components (Lelieveld, 167). Many polymers, such as polytetrafluoroethylene (PTFE or Teflon), are also porous, and therefore can harbor microorganisms and be difficult to clean. Polymers recommended by Lelieveld for use in food production are Polypropylene (PP), unplasticised Polyvinyl chloride (PVC), Acetal copolymer, Polycarbonate (PC), and High density polyethylene (PE) due to ease of cleaning and sanitation.

Elastomers are mainly used for gaskets and seals, which their high resilience to applied stresses and recovery after the stress is removed makes them particularly suited for. When selecting an elastomer for use, it is important to consider all the environments and stresses that the part could be exposed to in service to avoid premature failure. For instance, Ethylene Propylene Diene Monomer (EDPM) is not oil and fat resistant and should not be used for gaskets and seals exposed to those media. Lelieveld recommends the use of Ethylene Propylene Diene

Monomer (EPDM), Nitrile rubber, Nitrile/butyl rubber (NBR), Silicon rubber, and Fluoroelastomer (Viton).

The use of ceramics and composites is generally low in food service use. Ceramics are usually reserved for highly specialized applications such as active mechanical seals on rotating equipment. Composite materials are generally used only for dry storage applications where weight is a concern. For both ceramics and composites, it is important to consider the consequences of chipping and delamination, respectively, as these failure mechanisms could lead to product contamination (Lelieveld, 174).

Surface Finish – Surface finish is another important consideration in selecting an appropriate material for food service. Smooth surfaces are more easily cleaned of bacteria and other contaminates than rough surfaces. Therefore, it is recommended that surface roughness not exceed an Ra value of 0.8µm (Lelieveld et. al, 168). There are many surface treatments available for metallic materials provide such a surface finish. These processes include polishing, electro-polishing, that Cold-rolled Stainless Steels typically have an R_a value of 0.2µm to 0.5µm and require no additional surface treatments (Kalpakjian, 1104).

Joints and Fasteners – When designing joints with an emphasis on hygienic practices, the most important aspect is avoiding the creation of "shadow zones" or "dead zones", which are places that are hard to clean and visually inspect. In these shadow zones microorganisms and other contaminates can reach high levels over time. The dead zones then act as reservoirs for infectious agents and grime, contaminating nearby products and surfaces. Similarly, the equipment should be and free from crevices, sharp corners, and protrusions (Lelieveld, 8.1).

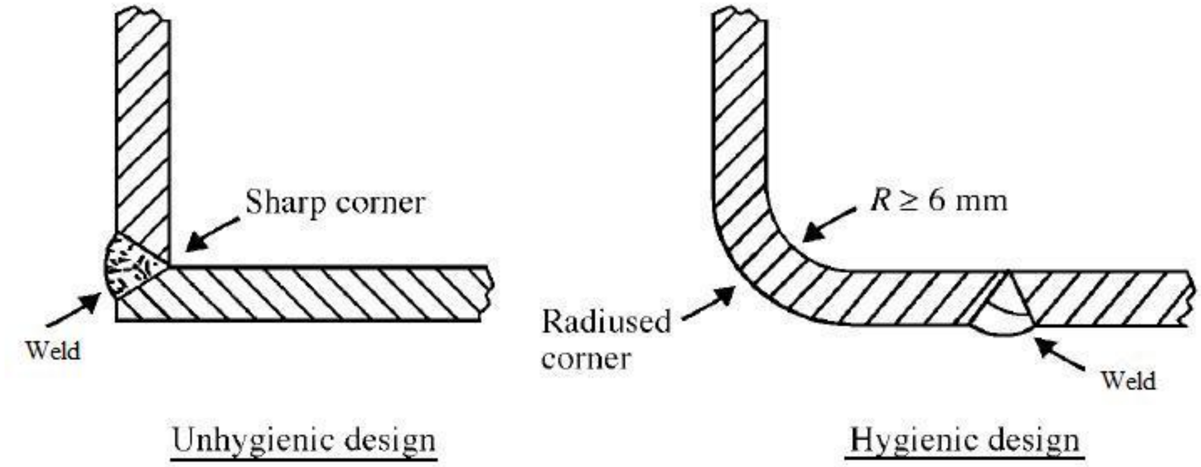


Figure 21. Hygienic and Unhygienic Design of Corners. From Lelieveld et Al.

When designing a joint, the preference is to use welding or continuous bonding (with a non-toxic agent) rather than fasteners, which create crevices that can harbor microorganisms, grime, and cause localized corrosion (Lelieveld, 126). Weld quality must be high to achieve sanitary conditions. All welds should be smooth, continuous and free of defects. The welds should also have low porosity and a very low level of slag inclusions. Both of these conditions can be achieved through proper selection of electrodes and filler metals, proper cleaning of the weld zone, and use of sufficient shielding gas (Kalpakjian, 962).

Special care must be taken when welding stainless steels to prevent a condition called sensitization. For austenitic stainless steels this sensitization effect occurs when heated from 500 to 950ºC (930 to 1740ºF), which occurs within the weld's HAZ. Inside of this temperature range, chromium-rich precipitates such as Cr23C6 form in the grain boundaries, leaving other areas with levels of chromium below that required to maintain passivity (Cramer, 304). These grain boundaries become anodic to the metal, leading to localized pitting and attack along the grain boundaries. To avoid sensitization, it is important to use low carbon variants of the selected stainless steel if it is to be joined by welding. For stainless steels commonly used in commercial kitchen applications, these would be SAE Grade 316L and 304L. Another solution is to use stainless steels with the addition of a preferential carbide former, such as Titanium (SAE Grade 321), or Niobium (SAE Grade 347).

Drainability – As noted earlier, stagnant water serves as an excellent breeding ground for microbes, and levels can quickly become high enough to contaminate food. Therefore, the elimination of areas where water can pool is an important design consideration for all equipment and preparation surfaces within kitchens or anywhere food is handled. Pooled water also increases the potential for corrosion by both increasing the time of exposure and concentrating contaminates during evaporation. An example of proper rim design is shown in Figure 22.

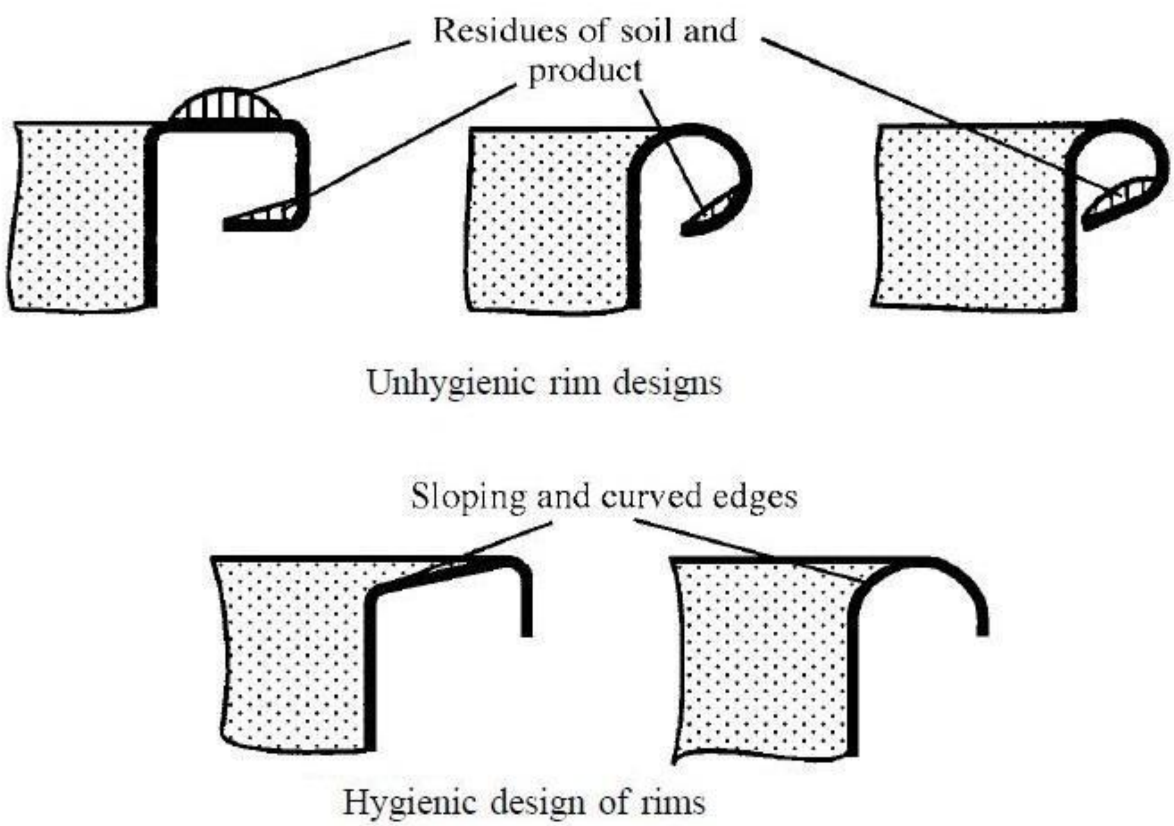


Figure 22. Drainability and Hygienic Design of Rims. From Lelieyeld et Al.

2.7 Worker Fatigue in Kitchens

Worker fatigue can be observed as a lessening of the capacity to perform, and a feeling of weariness in body or mental activity. In general, fatigue is linked to being tired and often times performing at a slower pace. With this said, the best way to check for fatigue is to look for a decrease in the rate of output or quality of output by the worker (Gilbreth, 427). Also, simple signs of weariness like yawning, bags under the eyes, and slower than normal movement are also valid indicators of fatigue.

There are several causes of worker fatigue in kitchens. Such causes include: posture, uncomfortable working equipment, extended duration of task, temperature, and thermal strain (Mitchell, 1). Out of all the sources of fatigue, temperature and thermal strain have the largest effect. Usually the two factors work off each other to create serious fatigue effects. Other factors such as poor lighting and poor ventilation are also known to cause fatigue (Gilbreth, 445). The importance of lighting and ventilation is discussed elsewhere in this chapter. However, there are also uncontrollable factors of fatigue in the kitchen. These factors depend on the worker's life style (Gilbreth, 445). Things such as amount of sleep and physical strain outside of the workplace cannot be controlled within the kitchen. Therefore, kitchens should only focus on the aspects of fatigue that they can eliminate, since not all fatigue can be eliminated.

Fatigue is a problem because it has negative effects in the workplace. First, efficiency is severely affected if employees are fatigued. Enormous amounts of waste are linked to fatigue, such as wasted material, product, and time. There also tends to be a lessening in both quality and quantity of output. A fatigued worker does about one-third of what they could do under anti-fatigue conditions (Gilbreth, 427). All of this is what minimizes efficiency. This means the kitchen will not reach max productivity if the workers are fatigued. All of this can result in a huge loss of profits and wasted money. Secondly, fatigue can lead to injuries in the kitchen. A survey of professional kitchen staff found that 75% of the kitchen workers reported pain related to the job (Mitchell, 3). Most of these injuries were caused by fatigue related incidents, most notably posture. It is important to look for fatigue all time for these reasons. Spotting fatigue can lessen the amount of waste and injuries within the kitchen.

2.7.1 Posture

Most work in a kitchen involves a static standing posture at a work area. After a while this can cause extreme fatigue in the workers. Prolonged standing can cause contact trauma and pain in the feet and ankles. Constant standing can also cause blood to pool in the lower extremities, which causes muscle fatigue and can result in pain (Mitchell, 4). Ideally, twenty minutes of sitting every hour will lessen the stress on the feet and slow the blood pooling (Gilbreth, 445). However, static standing isn't the only fatiguing posture in the kitchen. Bending and reaching also cause fatigue in the kitchen. Most bending and reaching occurs at countertops and over stoves. Extended periods of bending and reaching can cause muscle strain in the back and shoulders (Mitchell, 6). This over a rather short period of time may cause fatigue and pain in the worker.

2.7.2 Uncomfortable Working Equipment

Working equipment that is uncomfortable does not play as big of a role in fatigue as posture does. Nonetheless, it still can cause fatigue in a worker and reduce efficiency. Uncomfortable equipment mostly causes fatigue in the hand and forearm. This commonly happens because equipment does not properly fit the hand or the wrist is forced to a non-neutral angle. Tools that do not fit in the hand will cause the fingers to spread away from the palm, which significantly reduces grip strength. Now, more pressure is required to maintain control of the tool. This will eventually lead to fatigue of the hand muscles (Mitchell, 5). Other tools, like knives and spatulas, force the wrist to an un-natural angle while being used. This position is uncomfortable for most people and can lead to strain in the wrist with prolonged use. Tired hand and arms will lead to slower production from the workers. This is why ergonomic equipment should be used when possible.

2.7.3 Extended Duration of Task

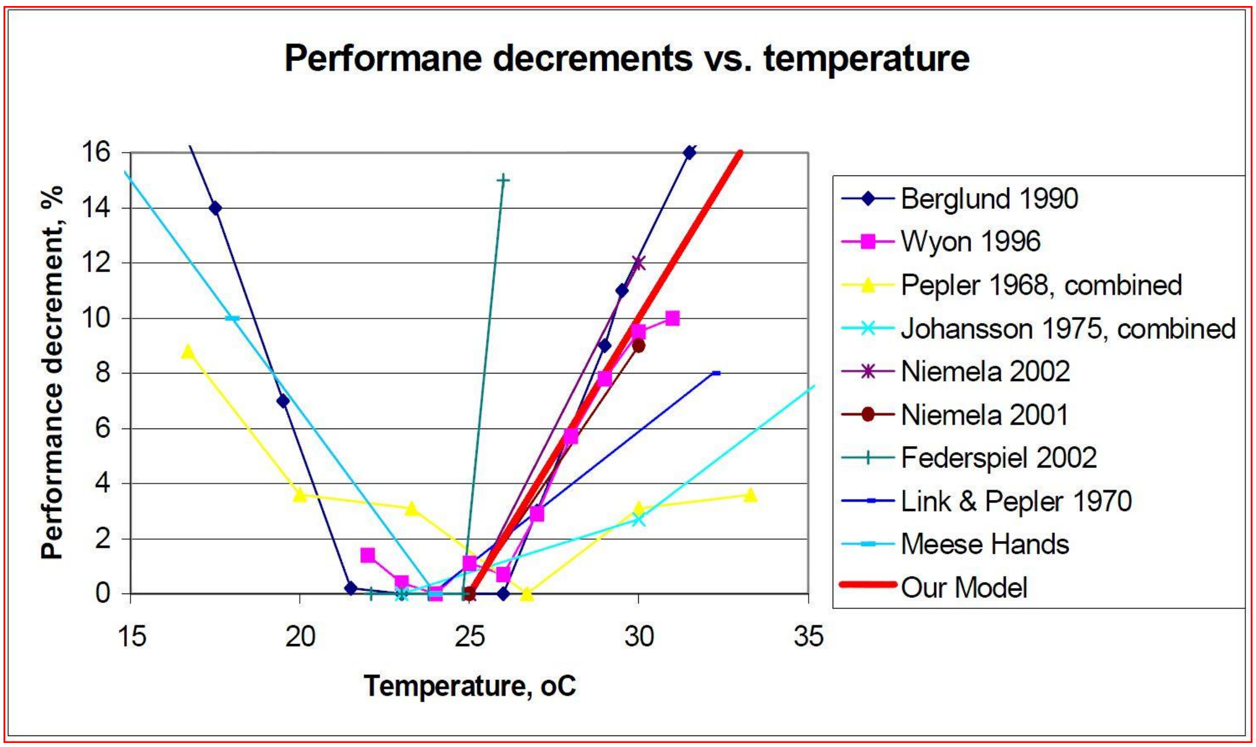
Extended tasks have more of an effect on mental fatigue than on physical fatigue. Such extended jobs in a kitchen like dish washing or food preparation can cause mental fatigue. This is because such tasks are repetitious and menial. After a period of time, this creates a sense of boredom. As a result, the worker tends to come to work more fatigued than the previous day and their daily productivity lessens (Gilbreth, 445). To prevent this mental fatigue, change the workers task every few hours to keep them moving and mentally alert. Preventing this mental fatigue will increase the energy of the working, and as a result, productivity and efficiency will increase as well.

2.7.4 Temperature and Thermal Strain

Temperature and thermal strain have the largest effect of fatigue on the workers. There is a general decrement in work performance when temperatures are not in the range of thermal neutrality (Seppanen et al, 1). This is cause by the thermal strain placed on the worker, which increases fatigue. On average, there is about a 2% decrease in work performance per degree Celsius, when the temperature exceeds 25^{o}C. When the work is physically demanding, there can be an 8% to 15 % reduction in productivity per degree Celsius. Surveys show that nearly 50% of workers feel that their working conditions are outside of their thermal comfort zone (Seppanen et al, 1). However, there is a comfortable temperature range that yields the most favorable work productivity.

Temperature variations within the range of 21°C to 25°C do not appear to have any significant effects on work performance. Here, there is no reduction of work speed; however, work speed starts to diminish per degree Celsius when it exceeds this range (Seppanen et al, 3). A graph of work decrement related to temperature is shown in Figure 23. The following model shows the relationship between decreased work productivity and temperature:

P (%) = 2*(Temp, °C) - 50



Courtesy of Seppanen, Fisk, and Faulkner

Figure 23. Chart of Performance Decrement with Increasing Temperature

In a kitchen, the working environment is known to be harsh due to the equipment that gives of heat. Studies show that kitchens have a higher ambient temperature than the comfortable range (Matsuzuki et al, 1). As the Tables 6, 7, and 8 show, the working environment in a kitchen is above 25^{o}C when equipment in being used. Such an environment can decrease productivity by 2% up to 14% based on the model. This is because the kitchen employees become fatigued as a result of thermal strain.

		Before exposure[1]				After exposure[2]				
		n	mean	SD	p-value[3]	n	mean	SD	p-value[3]	p-value[4]
Ambient dry-bulb temperature, °C										
Height, 90 cm[5]	IH stove	12	25.4	0.4	0.001	12	25.6	0.6	0.001	n.s.
	gas stove	12	26.4	0.3		12	26.9	0.5		0.001
Height, 120 cm[5]	IH stove	12	25.3	0.4	0.001	12	25.4	0.6	0.001	n.s.
	gas stove	12	26.0	0.5		12	26.5	0.5		0.001
Height, 150 cm[5]	IH stove	12	25.5	0.2	n.s.	12	25.6	0.5	0.010	n.s.
	gas stove	12	25.7	0.6		12	26.2	0.6		0.007
Relative humidity, %										
Height, 90 cm	IH stove	12	73.5	13.0	n.s.	12	74.4	10.6	0.032	n.s.
	gas stove	12	67.0	6.6		12	65.7	7.6		n.s.
Height, 120 cm	IH stove	12	74.2	13.3	n.s.	12	74.5	12.1	0.026	n.s.
	gas stove	12	67.2	6.6		12	64.7	7.5		0.008
Height, 150 cm	IH stove	12	74.6	12.4	n.s.	12	74.5	12.4	0.034	n.s.
	gas stove	12	67.2	6.7		12	64.9	7.6		0.025
Globe temperature, °C										
Height, 90 cm	IH stove	12	26.7	0.4	0.001	12	26.8	0.7	0.001	n.s.
	gas stove	12	37.5	0.7		12	38.7	0.7		0.002
Height, 120 cm	IH stove	12	27.2	0.4	0.001	12	27.3	0.6	0.001	n.s.
	gas stove	12	31.3	0.6		12	32.5	0.5		0.001
Height, 150 cm	IH stove	12	27.1	0.3	0.001	12	27.2	0.5	0.001	n.s.
	gas stove	12	28.7	0.5		12	29.6	0.4		0.001
Radiant heat index[6], °C										
Height, 90 cm	IH stove	12	1.3	0.1	0.001	12	1.2	0.2	0.001	n.s.
	gas stove	12	11.2	0.5		12	11.8	0.6		0.020
Height, 120 cm	IH stove	12	1.9	0.1	0.001	12	1.9	0.1	0.001	n.s.
	gas stove	12	5.2	0.5		12	6.0	0.4		0.001
Height, 150 cm	IH stove	12	1.7	0.1	0.001	12	1.7	0.1	0.001	n.s.
	gas stove	12	3.0	0.3		12	3.5	0.2		0.001
WBGT, °C										
Height, 90 cm	IH stove	12	23.7	1.1	0.001	12	23.9	1.3	0.001	n.s.
	gas stove	12	26.9	0.4		12	27.4	0.9		0.017
Height, 120 cm	IH stove	12	23.8	1.2	0.010	12	24.1	1.5	0.021	n.s.
	gas stove	12	24.8	0.7		12	25.3	1.0		0.005
Height, 150 cm	IH stove	12	24.0	1.2	n.s.	12	23.8	1.2	n.s.	n.s.
	gas stove	12	23.9	0.8		12	24.3	1.1		0.022

Ambient dry-bulb temperature: Temperature of the air
Relative Humidity: Amount of water vapor in the air
Globe Temperature: Uniform temperature of an enclosed space
Radiant heat index: Difference between ambient dry-bulb and globe temperature
WBGT: Temperature used to measure effects of wind speed and radiation

Table 6. Environment in Front of Stove Before and After Exposure to Heat Stress. Courtesy of Matsuzuki.

	Cooker	Air temperature, °C					Radiant heat index			WBGT, °C		
		Electric kitchen		Gas kitchen			Electric kitchen	Gas kitchen		Electric kitchen	Gas kitchen	
		n	mean SD	n	mean SD	*p*-value[1)]	mean SD	mean SD	*p*-value[1)]	mean SD	mean SD	*p*-value[1)]
Large-scale kitchen												
Elementary school	Kettle	239	23.8 ± 1.0	166	29.5 ± 3.5	0.001	0.72 ± 0.60	2.30 ± 2.11	0.001	21.1 ± 0.9	24.3 ± 2.6	0.001
	Oven	44	27.6 ± 3.4	29	34.4 ± 6.5	0.001	3.97 ± 2.23	3.06 ± 1.98	n.s.	24.5 ± 2.0	27.4 ± 4.3	0.001
Hospital	Kettle	273	21.2 ± 0.6	98	31.9 ± 1.7	0.001	0.95 ± 0.42	1.73 ± 0.97	0.001	19.3 ± 0.6	25.1 ± 1.2	0.001
	Cooking stove	279	21.7 ± 0.5	68	31.2 ± 1.5	0.001	0.81 ± 0.39	2.29 ± 1.19	0.001	19.9 ± 0.5	24.6 ± 1.2	0.001
Small-scale kitchen												
Pub	Cooking stove	23	29.8 ± 1.5	46	28.3 ± 1.8	0.001	5.83 ± 1.45	2.85 ± 1.95	0.001	23.9 ± 1.0	22.9 ± 1.7	0.001
	Grill	59	35.6 ± 6.5	71	32.2 ± 3.3	0.001	8.38 ± 3.23	10.82 ± 3.50	0.001	28.7 ± 4.6	27.3 ± 3.2	n.s.
	Fryer	33	30.0 ± 0.6	70	29.1 ± 1.8	0.001	3.69 ± 0.63	3.04 ± 2.69	n.s.	24.4 ± 0.5	23.0 ± 1.8	0.010
Family restaurant	Cooking stove	55	27.3 ± 0.9	53	29.6 ± 1.4	0.001	3.75 ± 0.84	5.64 ± 1.79	0.001	22.7 ± 0.8	25.3 ± 0.6	0.001
	Hot plate	77	29.2 ± 1.3	131	29.2 ± 1.3	n.s.	3.93 ± 1.22	5.05 ± 1.16	0.001	23.7 ± 1.3	24.9 ± 0.7	0.001
	Fryer	44	27.2 ± 0.9	20	26.1 ± 0.5	0.001	3.20 ± 0.95	2.77 ± 0.60	0.050	23.0 ± 1.5	22.8 ± 0.4	0.001
	Oven	54	29.4 ± 1.0	17	30.5 ± 0.4	0.001	2.86 ± 1.11	3.65 ± 0.87	n.s.	23.4 ± 0.7	24.5 ± 0.3	0.001
	Pasta boiler	35	26.8 ± 1.0	7	32.0 ± 0.5	0.001	2.08 ± 0.88	3.10 ± 0.72	0.001	22.5 ± 1.1	26.2 ± 0.3	0.001

Table 8. Air Temperature, Radiant Heat Index and WBGT Around Cooking Equipment. Courtesy of Matsuzuki

	Cooker	Heat source	Workers' ambient air temperatures, °C					Estimated ambient WBGTs[1)], °C			
			n	min.	max.	mean SD	*p*-value[2)]	min.	max.	mean SD	*p*-value[2)]
Large-scale kitchen											
Primary school	Kettle	Electricity	186	23.6	30.1	25.8 ± 1.2	0.001	21.0	29.9	22.5 ± 2.0	0.001
		Gas	292	28.6	39.9	33.9 ± 2.4		23.7	31.8	27.5 ± 1.7	
	Oven	Electricity	21	25.3	33.1	28.2 ± 1.8	0.001	21.0	21.8	21.3 ± 0.2	0.001
		Gas	14	32.4	38.3	35.6 ± 1.6		21.4	21.7	21.6 ± 0.2	
Large-scale kitchen											
Hospital	Kettle	Electricity[3)] Gas	153	26.3	33.1	30.0 ± 1.9		22.7	31.7	24.8 ± 1.5	
	Cooking stove	Electricity	20	22.4	26.4	23.9 ± 1.1	0.001	21.9	23.0	22.5 ± 0.3	0.001
		Gas	157	28.7	42.1	31.5 ± 2.1		22.7	24.9	24.1 ± 0.6	
Small-scale kitchen											
Pub	Cooking stove	Electricity[3)] Gas	20	25.7	30.1	28.1 ± 1.3		20.6	24.5	22.7 ± 1.2	
	Grill	Electricity	12	26.0	28.3	27.1 ± 0.8	0.001	23.2	33.6	26.9 ± 3.6	n.s.
		Gas	32	29.1	41.7	32.0 ± 2.7		21.9	32.0	25.3 ± 2.2	
	Fryer	Electricity[3)] Gas	26	27.8	40.8	31.2 ± 3.3		21.9	36.4	25.4 ± 3.4	
Small-scale kitchen											
Family restaurant	Cooking stove	Electricity	76	23.1	32.9	28.1 ± 1.4	0.001	22.5	28.3	25.3 ± 1.2	0.032
		Gas	61	26.5	36.3	31.7 ± 2.6		24.2	28.3	25.8 ± 1.1	
	Hot plate	Electricity	199	25.9	35.3	28.7 ± 1.6	0.001	20.1	28.7	23.9 ± 1.3	n.s.
		Gas	63	28.5	35.8	32.1 ± 1.6		22.5	26.6	23.9 ± 0.8	
	Oven	Electricity	15	25.7	31.4	28.2 ± 1.4	0.007	22.8	25.3	23.9 ± 0.9	n.s.
		Gas	9	26.5	37.8	33.8 ± 4.7		22.3	24.8	23.6 ± 0.8	
	Pasta boiler	Electricity	2	27.2	27.5	27.4 ± 0.2	0.050	23.0	23.0	23.0 ± 0.1	n.s.
		Gas	14	28.2	36.4	33.0 ± 2.9		22.3	24.0	23.0 ± 0.8	

Table 7. Workers' Ambient Air Temperature in Different Types of Kitchens. Courtesy of Matsuzuki

Thermal strain occurs under elevated temperature outside of the thermal comfort zone, and has psychological and physiological effects on workers in a kitchen. Psychologically, employees feel that the workload is considerably harder outside of the thermal comfort zone. This is because a high temperature range increases the feeling of workload (Matsuzuki et al, 6). Physiologically, heat strain causes increased heart rate, increased skin temperature, increased oxygen uptake, and increased fluid loss (Matsuzuki et al, 7). Under elevated temperatures, the volume of blood circulating increases, and in turn the heart rate increases under heat stress. Under heat strain, the average heart rate in a kitchen is 107 bpm and average fluid loss is 0.30 kg/h. This indicates an increase in fatigue associated with an increase in heat stress, and results of this can be seen in Figure 24, and Tables 9 and 10.

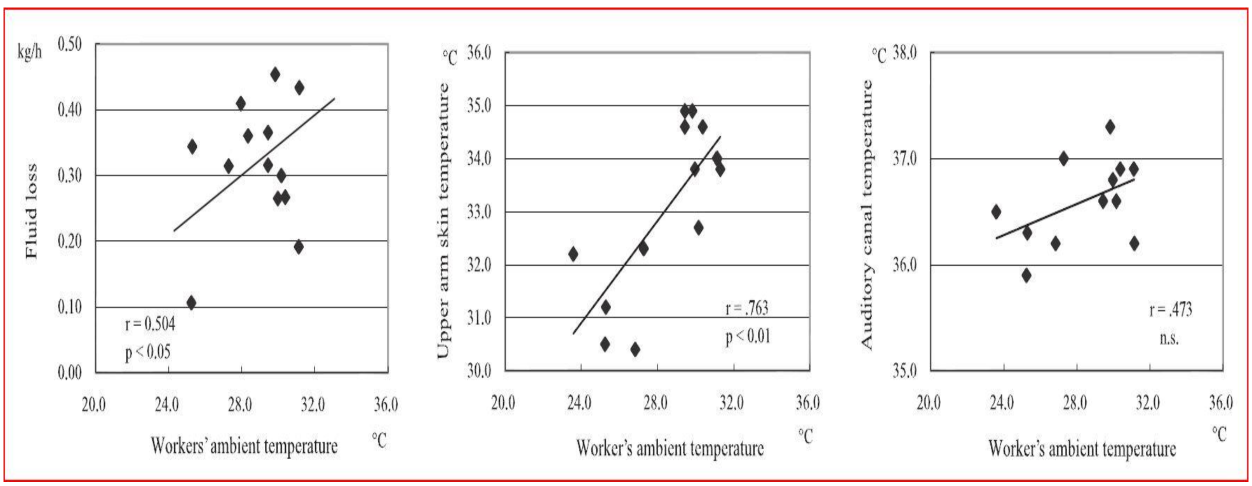


Figure 1. Relationship between fluid loss, skin temperature, and canal temperature relative to ambient temperature. All indicate a positive correlation.

Physiological items		Before exposure[1)] n	mean	SD	p-value[3)]	After exposure[2)] n	mean	SD	p-value[3)]	p-value[4)]
Weight, kg	IH stove	12	63.1	7.3	n.s.	12	63.0	7.3	n.s.	0.001
	gas stove	12	62.9	7.1		12	62.8	7.1		0.001
Heart rate, bpm	IH stove	11	78.6	9.8	n.s.	12	101.0	13.7	n.s.	0.001
	gas stove	12	76.6	10.2		12	108.8	16.9		0.001
Systolic blood pressure, mmHg	IH stove	11	113.8	9.3	n.s.	12	124.3	12.3	n.s.	0.008
	gas stove	12	115.9	11.3		12	128.0	11.1		0.042
Diastolic blood pressure, mmHg	IH stove	11	71.5	6.3	n.s.	12	84.3	7.4	n.s.	0.001
	gas stove	12	72.8	7.9		12	84.8	6.6		0.001
Double product, bpm*mmHg	IH stove	11	8,931	1,535	n.s.	12	12,505	2,201	n.s.	0.001
	gas stove	12	8,864	1,643		12	13,758	1,891		0.001
Oxygen uptake, ml*kg^{-1}*min^{-1}/kg	IH stove	11	4.3	0.7	n.s.	11	5.4	1.0	0.006	n.s.
	gas stove	12	4.6	1.4		12	6.5	0.8		0.001
Amount of activity, METs	IH stove	12	1.1	0.2	n.s.	10	1.6	0.2	n.s.	0.001
	gas stove	12	1.1	0.3		12	1.8	0.3		0.001
Antebrachial skin temperature, °C	IH stove	12	34.2	1.1	n.s.	11	36.8	0.5	0.001	0.001
	gas stove	12	34.1	1.1		12	39.7	1.1		0.001
Abdominal temperature, °C	IH stove	11	34.2	0.9	n.s.	11	35.2	0.7	0.001	0.001
	gas stove	12	34.2	0.8		12	38.4	0.8		0.001
External acoustic meatus temperature, °C	IH stove	12	36.3	0.3	n.s.	11	36.4	0.3	0.001	n.s.
	gas stove	12	36.1	0.3		12	37.2	0.6		0.001
Rectal temperature, °C	IH stove	12	37.1	0.3	n.s.	11	37.2	0.3	n.s.	0.009
	gas stove	12	37.1	0.3		12	37.3	0.3		0.005

Table 10. Physiological Responses Before and After Heat Exposure in Kitchens. Courtesy of Matsuzuki.

			Cooker proximity time[2)]			Workers' ambient temperature °C			Fluid loss		Upper arm skin temperature, °C			Auditory canal temperature, °C			Heart rate, bpm			Amount of activity, METs		
subject			n	min	%[3)]	mean SD	p-value[4)]	p-value[5)]	kg	kg/h	min	max	mean SD	min	max	mean SD	min	max	mean SD	min	max	mean SD
Large-scale kitchen																						
1	Primary school	Electric kitchen	271	74	27.3	25.2 ± 1.2	0.001	1–3,4	0.48	0.11	27.6	34.1	30.5 ± 1.4	35.5	36.2	35.9 ± 0.2	84	189	107 ± 26	1.0	2.8	1.4 ± 0.4
2			279	51	18.3	25.3 ± 0.9		2–3,4	1.60	0.34	27.3	33.6	31.2 ± 1.5	36.1	36.5	36.3 ± 0.1	84	118	102 ± 5	1.0	3.3	1.9 ± 0.6
3		Gas kitchen	169	79	46.7	31.1 ± 3.0		3–1,2,4	0.54	0.19	32.4	35.9	34.0 ± 1.1	36.3	37.5	36.9 ± 0.4	69	158	91 ± 17	1.0	2.4	1.4 ± 0.3
4			229	58	25.3	30.4 ± 3.1		4–1,2,3	1.02	0.27	31.7	37.3	34.6 ± 1.6	36.3	37.4	36.9 ± 0.4	74	183	113 ± 32	1.0	3.3	1.6 ± 0.5
5	Hospital	Electric kitchen	345	68	19.7	23.6 ± 1.4	0.001	5–6,7,8,9	0.92	0.16	30.2	35.0	32.2 ± 0.6	36.2	36.9	36.5 ± 0.1	84	144	114 ± 11	1.1	3.8	2.7 ± 0.6
6		Gas kitchen	185	42	23.0	29.8 ± 2.2		6–5,	1.40	0.45	33.0	36.2	34.9 ± 0.7	36.9	37.5	37.3 ± 1.1	108	162	120 ± 9	1.6	4.5	2.9 ± 0.7
7			190	57	30.0	29.4 ± 1.6		7–5,8	1.00	0.32	33.3	36.7	34.9 ± 0.9	36.3	36.9	36.6 ± 1.1	76	177	101 ± 24	1.0	4.4	2.0 ± 1.2
8			188	39	20.7	30.2 ± 1.2		8–5,7,8	0.94	0.30	29.6	34.4	32.7 ± 1.2	36.3	36.8	36.6 ± 1.1	74	180	103 ± 27	1.0	4.2	2.0 ± 0.6
9			197	47	23.9	29.4 ± 1.5		9–5,8	1.20	0.37	32.1	37.0	34.6 ± 1.6	—	—	— —	106	150	124 ± 10	1.5	3.8	2.9 ± 0.7
Small-scale kitchen																						
10	Pub	Electric kitchen	126	8	6.3	27.3 ± 1.5	0.001	10–12	0.66	0.31	30.1	34.5	32.3 ± 1.0	36.9	37.1	37.0 ± 0.1	93	165	116 ± 16	1.0	2.2	1.3 ± 0.2
11		Gas kitchen	75	8	10.7	26.8 ± 2.1		11–12	0.14	0.11	29.2	33.2	30.4 ± 0.7	36.1	36.7	36.2 ± 1.3	92	176	107 ± 18	1.5	4.4	2.4 ± 0.6
12			68	21	30.9	30.0 ± 2.9		12–10,11	0.30	0.26	33.3	34.5	33.8 ± 0.3	36.7	37.0	36.8 ± 0.1	93	165	113 ± 28	1.3	4.1	1.8 ± 0.7
13	Family restaurant	Electric kitchen	126	22	17.5	27.9 ± 1.1	0.001	13–15,16	0.86	0.41	—	—	— —	—	—	— —	—	—	— —	—	—	— —
14			150	53	35.3	28.3 ± 1.5		14–15,16	0.90	0.36	—	—	— —	—	—	— —	—	—	— —	—	—	— —
15		Gas kitchen	116	25	21.6	31.3 ± 2.7		15–13,14	0.82	0.42	32.4	35.8	33.8 ± 0.9	—	—	— —	75	106	88 ± 5	1.1	2.9	1.9 ± 0.4
16			119	51	42.9	31.1 ± 2.8		16–13,14	0.86	0.43	32.2	35.2	34.0 ± 0.8	35.6	36.7	36.2 ± 0.2	80	112	98 ± 7	1.1	3.6	2.3 ± 0.5

Table 9. Thermal Strain Statistics in Kitchens. Courtesy of Matsuzuki

2.7.5 Fatigue Prevention

The best way to prevent fatigue is to prevent thermal strain. This can be done with a ventilation and air-cooling system that will keep the ambient air temperature within the range of 21°C to 25°C. This is discussed in detail elsewhere in the chapter. Work gloves and chef's coat can also help prevent thermal strain because they form a protective barrier (Matsuzuki et al, 11). However, there are many other ways to prevent fatigue in a kitchen.

Rest intervals are very important to prevent fatigue. This will allow the worker to rest and recuperate from the tasks at hand (Gilbreth, 445). Also, if the work can be done seated rather than standing, then this will relieve the stress on the feet and ankles. If the work cannot be done seated, then anti-fatigue mats will also reduce the stress of standing. An anti-fatigue mat can reduce the stress on the feet and ankles from 17 psi to 2 psi (Horowitz, 1).

Another way to prevent fatigue is to implement the use of ergonomic equipment. Counter surfaces should be adjustable if possible. If there is no way to make them adjustable, there should be various heights throughout the kitchen. This will minimize forward bending and shoulder elevation (Mitchell, 5). Also, a cutout design of a countertop will minimize forward lean and reaching. A cutout design can be seen in Figure 24. Ergonomic equipment should also be utilized. This equipment will keep the wrist in a neutral position and minimize finger pinch. An ergonomic knife and Spatula can be seen in Figures 25 and 26. This will reduce strain in the wrist.

Providing sufficient lighting will also reduce fatigue in the kitchen. In conjugation with general lighting, all other workspaces should be additionally lighted. This is also discussed in detail elsewhere in this chapter.

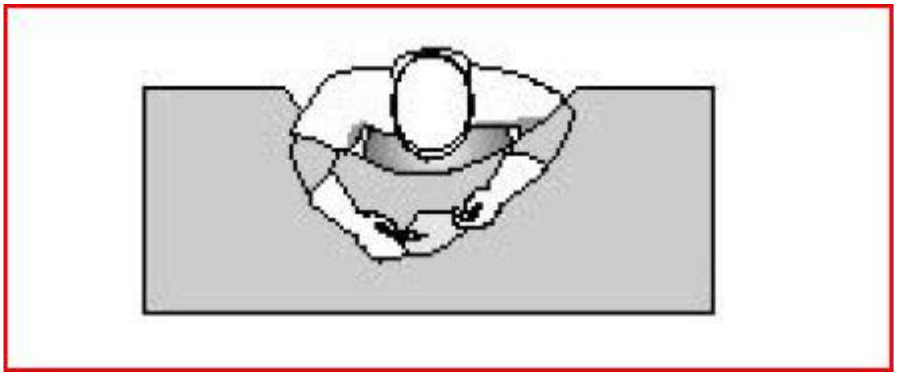


Figure 24. Overhead View of a Cutout Work Area. This Reduces Forward Lean and Reaching

Figure 25. Example of an Ergonomic Knife

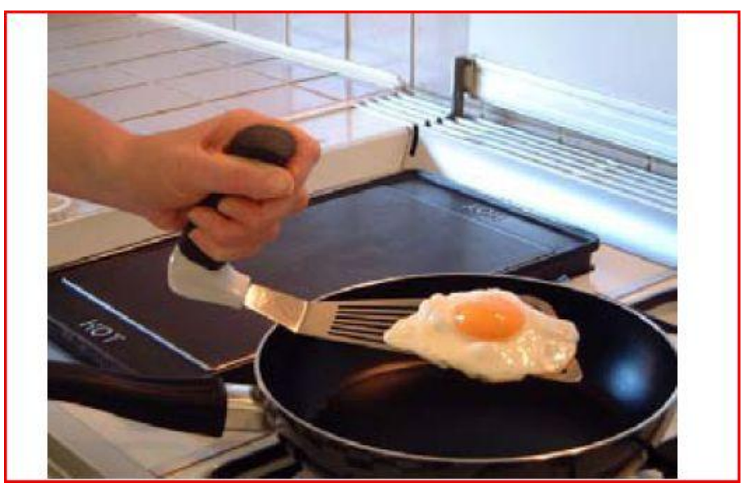


Figure 26. Example of an Ergonomic Spatula

2.8 Alternate Uses

The primary function of the mobile kitchen is obviously to make and sell food efficiently. However, in order to separate the kitchen from other food vendors and restaurants it should have alternate uses. Alternate uses allow the kitchen to be useful and continue to make a profit even while it is unable to sell food. Desirable alternate uses will make money through advertising or other sales, or they will provide a service that will draw customers to the kitchen.

Alternate uses that earn revenue are either advertising based or sales based. Revenue gained through advertising will be affected by the popularity of the kitchen; the more customers that visit the kitchen, the more advertisers will be willing to pay. Possible types of advertising include:

2.8.1 Posters/Digital Screens

In a city setting, the kitchen will often be facing a sidewalk, with a street behind it. This opens the opportunity to use the rear wall of the mobile kitchen for advertising. Advertisers will pay to have their advertisements prominently positioned where passing motorists will see them. Additional revenue can be gained by replacing a standard poster advertisement with a digital display. Digital displays are computer-controlled electronic screens. Advertisers are willing to spend more on digital displays because they have numerous benefits. The board alternates between messages, displaying one for about ten seconds before switching the next. The most common size for digital displays is the poster size, which is 10’x21’. Almost any size can be implemented, however, since it only requires a computer and an LCD screen.

The ease at which messages can be changed is an attractive selling point to advertisers. They can update of completely change their message with a simple e-mail. This allows advertisements to be updated constantly, with current information about news or events. The average cost of advertising on a digital display in New England is $1,700 per month, meaning the return on investment will be large and immediate.

2.8.2 Paper Product Advertising

Many advertisers will pay to advertise their product on cups, napkins, and other products. Some will even cover the entire cost of the products in order to have their company’s name, logo, or information printed on it. This can save the mobile kitchen the entire cost of the paper products.

2.8.3 Single Sponsor Representation

The mobile kitchen can receive benefits from a soft drink company (The Coca-Cola Company or PepsiCo) if it is exclusive. Meaning the company will give the kitchen a greater share of the profits, and sometimes pay for the electricity required to refrigerate the beverages.

2.9 Location

The portability of a mobile kitchen allows it to be set up in a variety of locations. Specifically food carts tend to be most profitable in the following locations: disaster zones, downtown business districts, concerts, college areas, fairs, other outdoor events, carnivals construction sites, sporting events and weddings. These locations all have high foot traffic and tend to lack restaurants capable of serving large amounts of customers in a quick and convenient manner.

It is important that the mobile kitchen is designed to be practical for city usage. Metropolitan areas generally have denser population distributions and more pedestrians. Individuals traveling on foot or using public transportation would be more likely to patronize a mobile kitchen than those traveling by car. This makes metropolitan areas ideal locations to establish mobile kitchens.

To investigate a mobile kitchen's potential in metropolitan areas, we used Boston, Massachusetts as a model. Boston is the largest city in New England, with a population of over 600,000. With an area of less than 50 square miles, this makes Boston a very dense city. The greater Boston area also has a total of 52 colleges and universities, which means it has many young adults who are more likely to be on foot and looking for inexpensive food.

Boston currently has 20 food truck companies in operation, at various locations throughout the city. The Official Website of the City of Boston lists all food trucks in operation by date and time and location. Figure 27 is an interactive map provided by the City of Boston to view the up to date locations of all its food trucks. The map can be edited to display only certain food truck chains, and which are available by day and time.

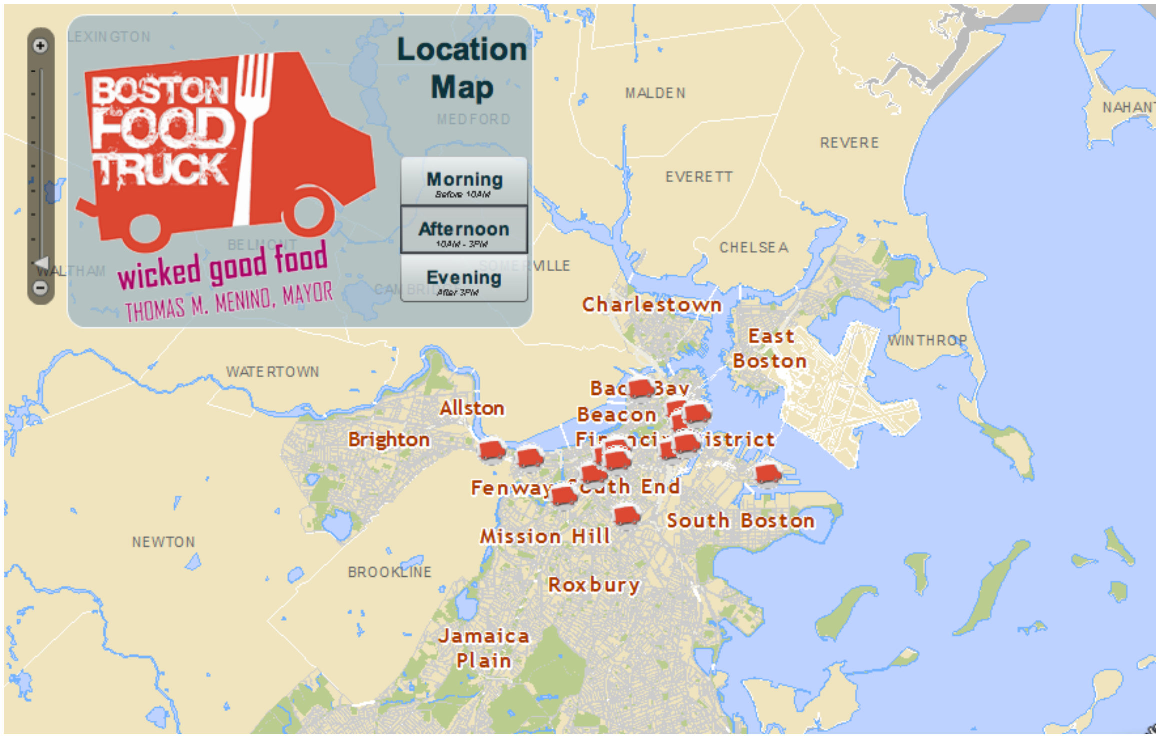


Figure 27. Boston Food Truck Map: Afternoon Locations

Many current food trucks in the Boston area cater one specific food product or type products. For example, some of the most popular food trucks include Grilled Cheese Nation, Kick*ss Cupcakes, and Go Fish, which predominantly serve grilled cheese, cupcakes, and seafood, respectively. Our mobile kitchen will have the ability to serve a variety of different food types to cater to many different consumers.

CHAPTER 3. DESIGN OF THE IMPROVED MOBILE KITCHEN UNIT

Introduction

The objective of our proposed design is to address the multitude of problems found in current mobile food preparation, which undermine their safety, productivity and profitability. Our group aims to reduce the costs of preventable food-borne illnesses and work related injuries due to mobile kitchens through our improved design. The projects main constraints throughout the design phase were mobility, size and functionality, all of which are addressed within the final design.

3.1 Overview of Operation

The final mobile kitchen design is intended to operate as part of a coordinated, multi-unit system. Although the kitchen is entirely capable of operating on its own, we believe that the best customer experience and highest profitability would be delivered by a system of multiple kitchens operating in conjunction. Important individual components of this system will be discussed in further detail later in the chapter.

The overall system consists of three basic components: mobile kitchen units, resupply vehicles, and a centralized control system responsible for routing orders and deliveries. The mobile kitchen units, which our design work focuses on, are responsible for the final preparation and presentation of food to the customer. Each of these units would operate more or less autonomously, with limited interaction with the other food preparation and serving units. Each of these units would have a centralized computer that would incoming track orders and remaining inventory. When the computer receives input that the inventory is getting low, it sends a signal to the centralized control system requesting to be resupplied. This request is routed to the closest resupply vehicle, which then resupplies the unit.

Customers can place their orders in two ways. First, they can place their order directly at the mobile kitchen. Alternately, the customer can place their order using an online service from their computer or phone. This method is becoming increasingly popular with restaurants in cities, but has not yet been adopted by many mobile food preparation kitchens. Online ordering is likely to become widespread in the near future due to convenience and increasing use of mobile phones with internet capability. Our kitchen system is designed to facilitate the use of online ordering services. If a customer places an order online, the centralized control system routs the order to either the kitchen closest to the customer's location, or the location of a kitchen specified by the customer in the order. The mobile kitchen unit then prepares the order to the customer's specifications, and has it waiting and ready for pickup when they arrive. This method also allows the customer the flexibility of paying either online or at the mobile kitchen unit, depending on their preferences.

3.2 Design Process of the Mobile Kitchen Unit

The design process began with the design of the basic floor plan. This is an important step because equipment and other items in the kitchen will be placed according to this plan. To create the floor plan, layout considerations from Section 2.1.1 were analyzed. It was determined that a modified U-shaped layout would be beneficial to the entire cooking process. It would maximize useable space within the mobile kitchen, while minimizing walking distance between work centers. This layout would also allow the design to incorporate a "work triangle," detailed in Section 2.1.4. The work triangle concept is an arrangement that allows the cook to move easily between the areas that are most commonly used. In this case, the three most used areas are the refrigerator, sink, and prep area. The work-triangle is shown incorporated into the design in Figure 28.

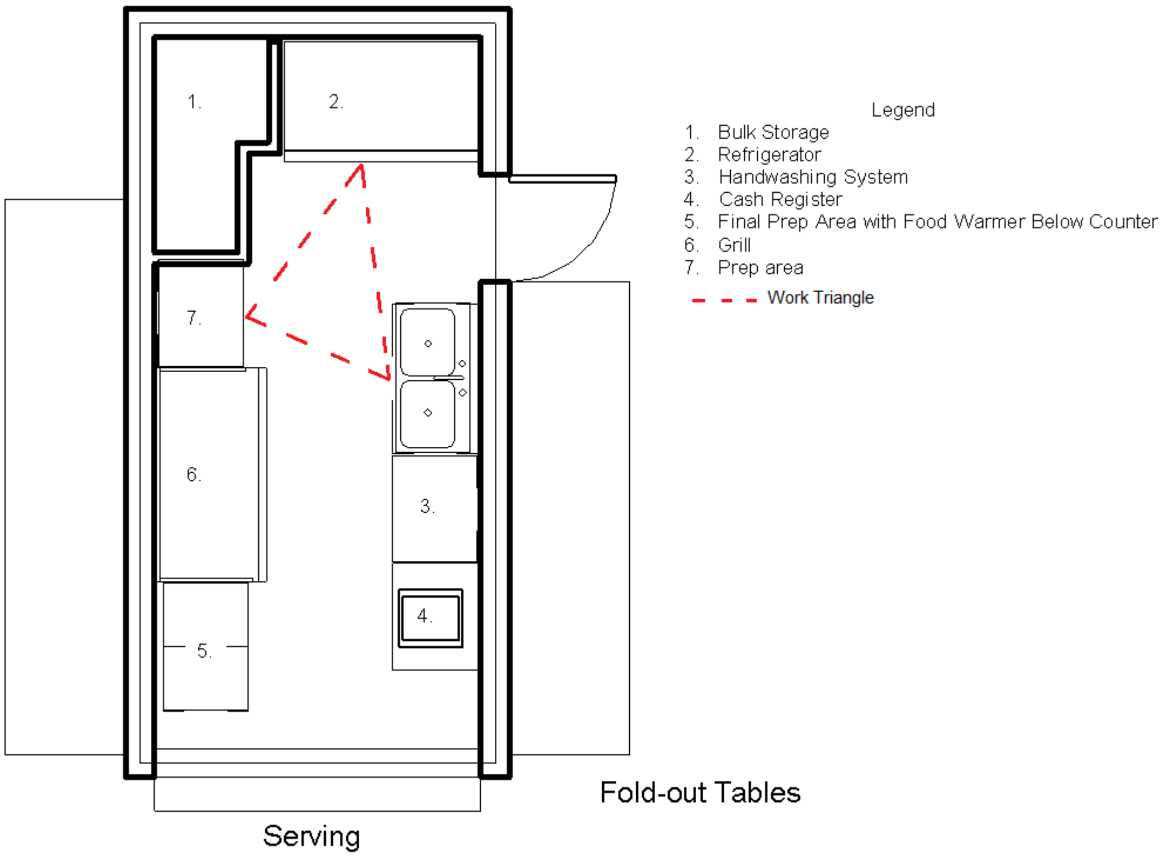


Figure 28. Work Triangle included in the Design Layout

This design also utilizes the flow of materials detailed in Figure 2. The food and ingredients will generally flow from the storage areas to the serving area in one direction to maximize efficiency. It will be moved from the storage area to the prep areas where the raw food will be prepared to cook. From the prep area, the food will go directly to the grill to be cooked. Once the food is done cooking, it will be taken off the grill and placed on the final prep area, where the final preparations will be made. The food will then be served to the customer though the serving window. As depicted in Figure 29, this will all be done while maintaining a logical, direct path

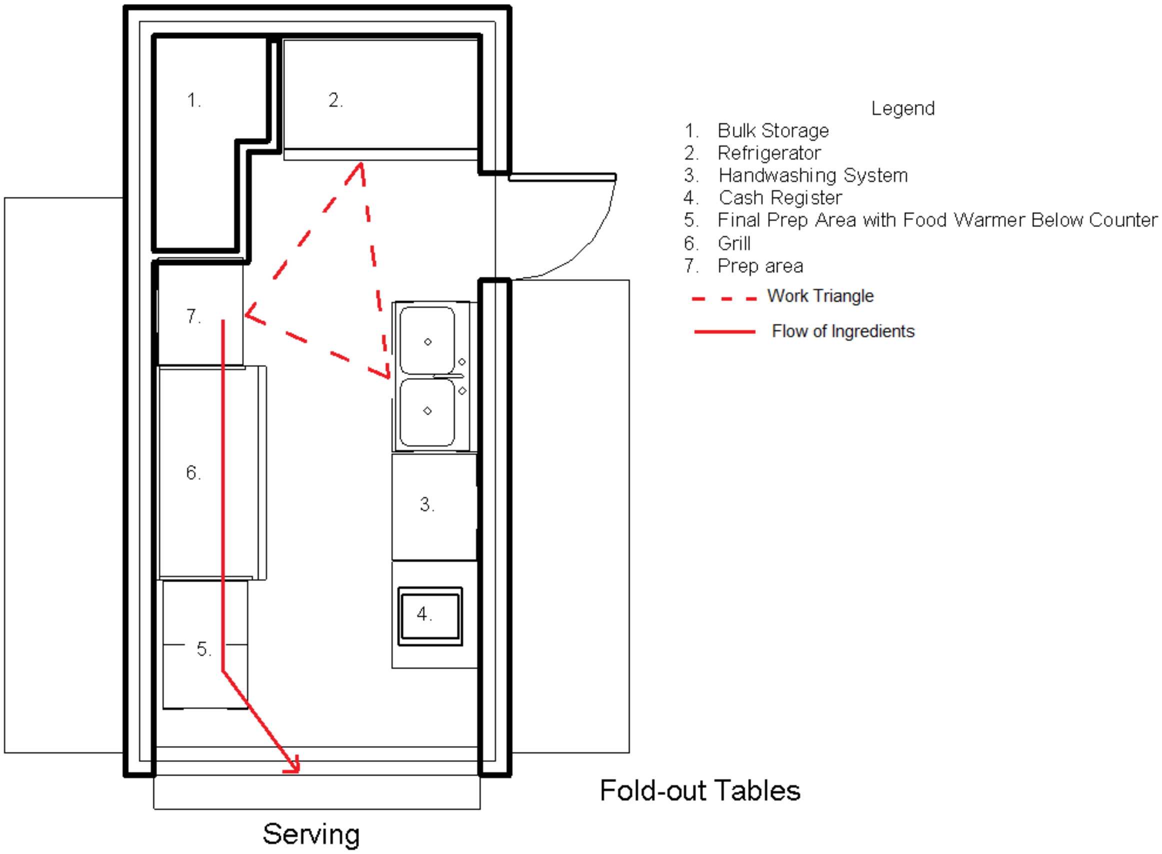


Figure 29. Flow of Ingredients within the Mobile Kitchen

The design layout was initially sketched by hand, a model kitchen was then created using Autodesk Revit Architecture. Revit Architecture creates a three-dimensional, parametric model of the kitchen. This allows a two-dimensional layout and three-dimensional model of the kitchen to be created simultaneously. The three-dimensional model was then rendered to produce interior and exterior views of the mobile kitchen model, as shown below in figures 30 and 31.

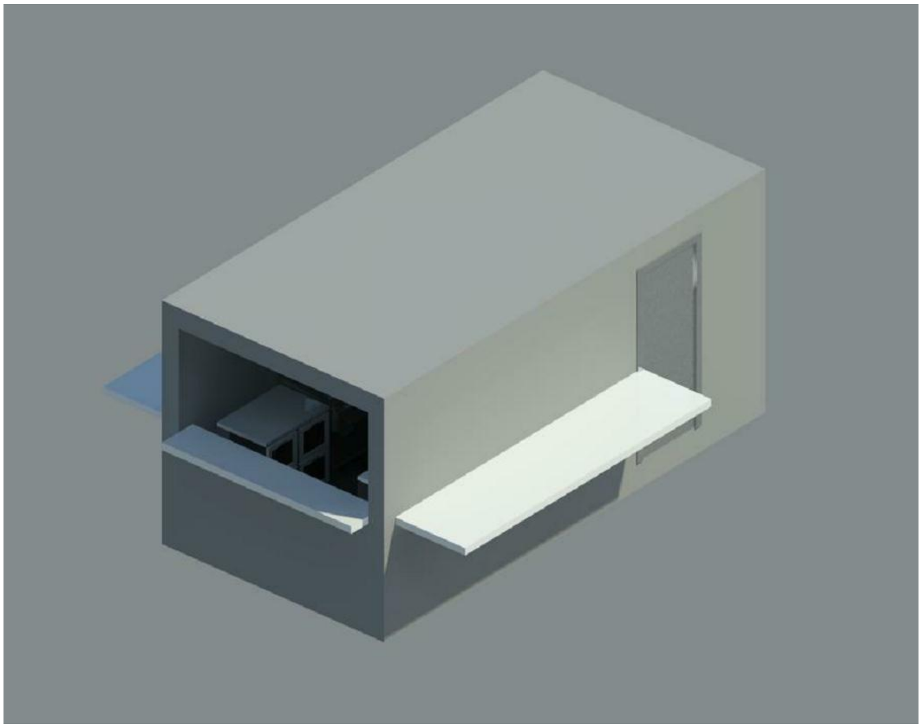


Figure 30. Exterior Rendering of the Mobile Kitchen Design

Figure 31. Interior Rendering of the Mobile Kitchen

The Revit models were then reproduced in SolidWorks to include cooking equipment from the Revit design and incorporate the HVAC system. This model is shown in Figures 32 and 33. In these models, magenta represents the grill, purple represents the warming tray, teal represents the hand washing unit, and yellow represents the sink. The HVAC system is not pictured in this Figure.

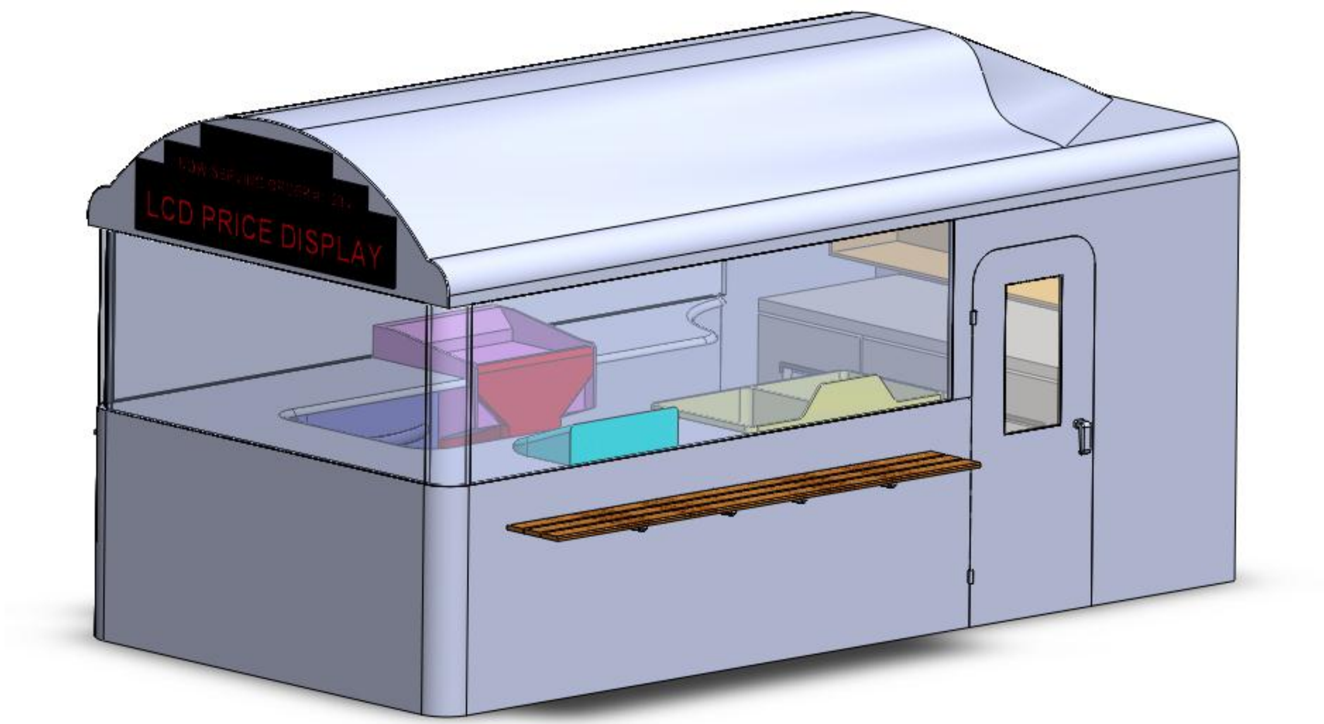


Figure 32. SolidWorks Model of the Mobile Kitchen

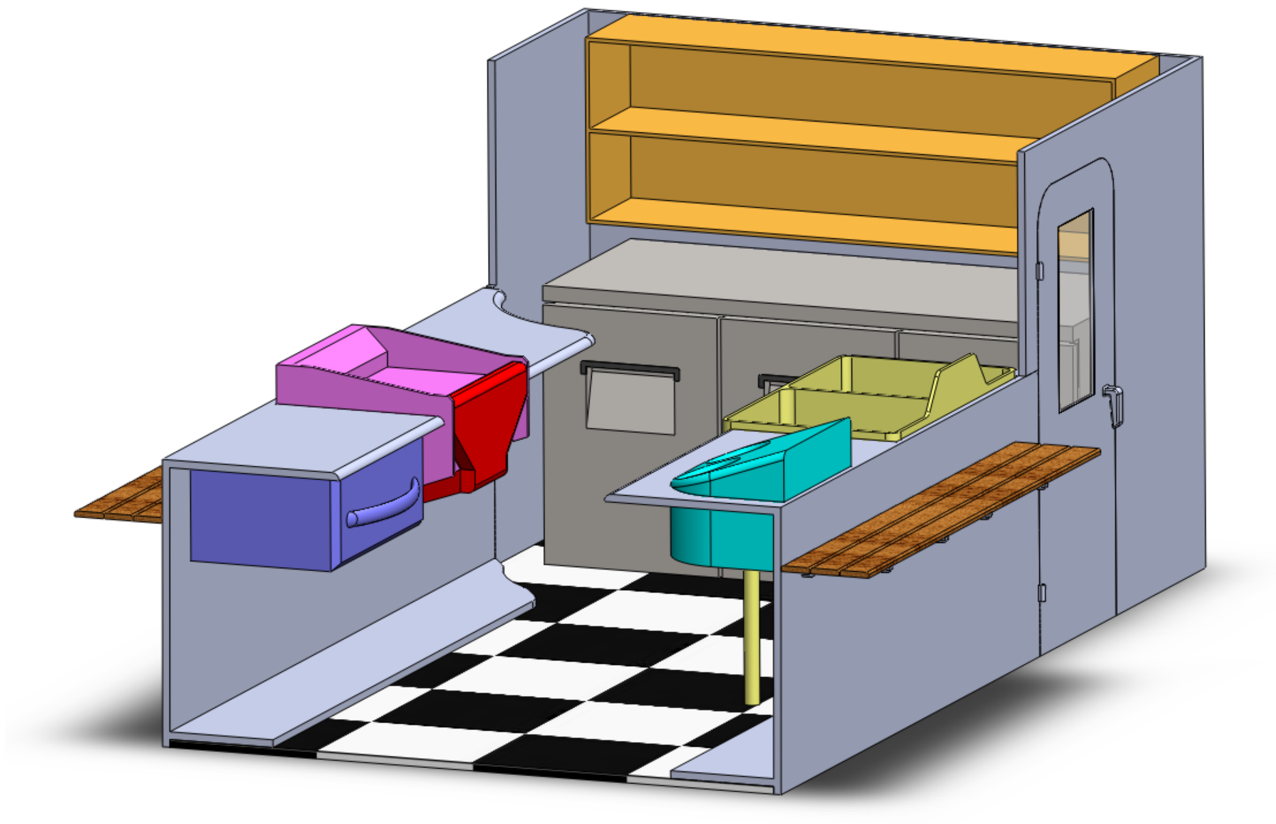


Figure 33. Cross-Section of the SolidWorks Model

These models incorporate the ideas and designs from each iteration of the design process. With each design building off of the last, our final design meets the layout needs of a mobile kitchen. These intermediate iterations of the design can be found in Appendix A.

3.3 HVAC System Design

Most current mobile kitchens lack an HVAC system designed in a cohesive manner. Many mobile kitchens rely entirely on natural ventilation. This limits the range of operating environments, as the user has very little control of the ventilation process. Natural ventilation is also not very effective in removing cooking effluent from grills that can severely affect the air quality within the kitchen. One advantage of natural ventilation is that is uses no energy, which is an attractive feature for any system. An example of this type of ventilation system can be seen in Figure 34.

Figure 34. Mobile kitchen with Natural Ventilation

The next best system is one that makes use of a hybrid ventilation system, relying on both mechanical and natural means to ventilate the kitchen. A good example of this can be seen in Figure 35, which is a German mobile kitchen.

Figure 35. German Mobile Kitchen with Hybrid Ventilation

The roof of the German kitchen has a series of exhaust ducts to which are powered by small fans. These ducts pull cooking effluent from the grill out of the kitchen and rely on the negative pressure created within the kitchen to pull outside air into the kitchen through the large serving window. This system improves air quality significantly; however it is still limited to operation in conditions where the ambient temperature is within comfortable ranges.

Most other mobile kitchens on the market make use of a fully mechanical ventilation system, conditioning all outside air before removing it through exhaust hoods. This HVAC process gives very good control of inside air quality and thermal comfort, but it comes at the cost of high energy usage.

In our kitchen, the HVAC system design combines the low energy usage of a natural ventilation system with the comfort and control of a mechanical system. Design of the HVAC system began with assessment of the major heat loads found within a kitchen. Figure 36 shows a cutaway view of the kitchen with the components of the HVAC system shown. Green represents the general ventilation ducting and HVAC unit itself, which is hidden under the roof during normal operation. In the Figure, red represents the makeup air system and exhaust ducting associated with the grill. A top-down view of the HVAC system is shown in Figure 37.

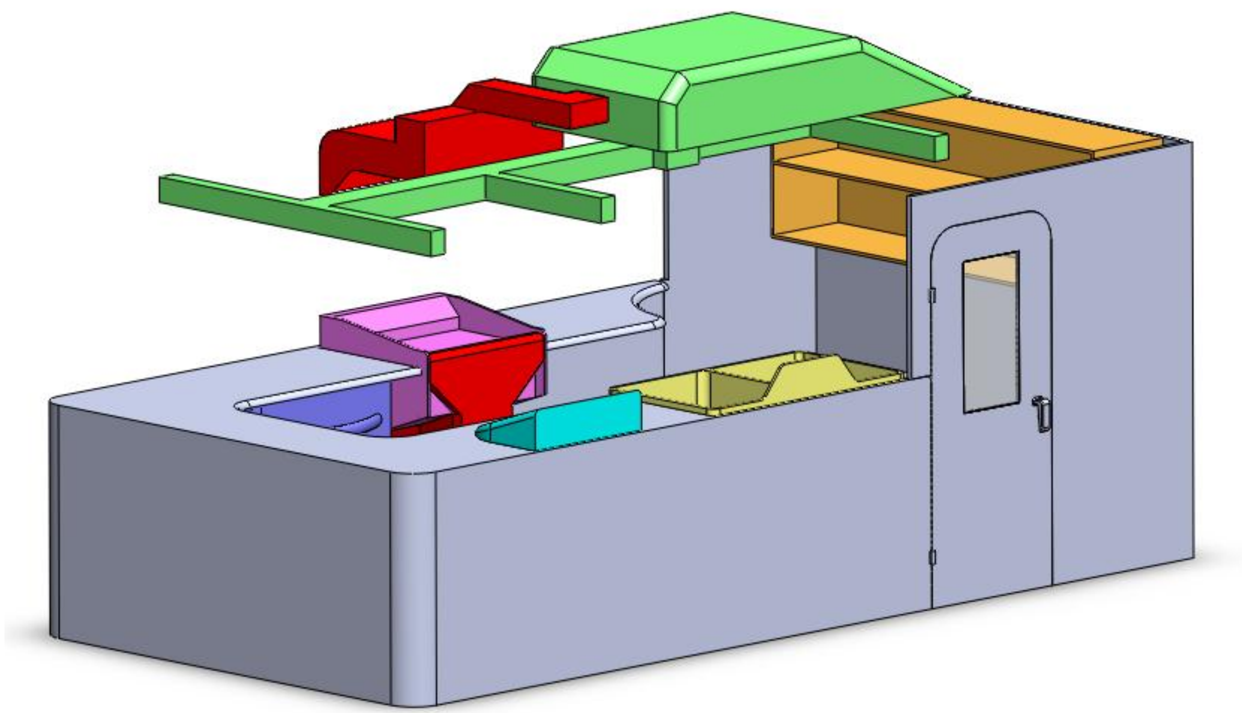


Figure 36. Section View Showing HVAC System

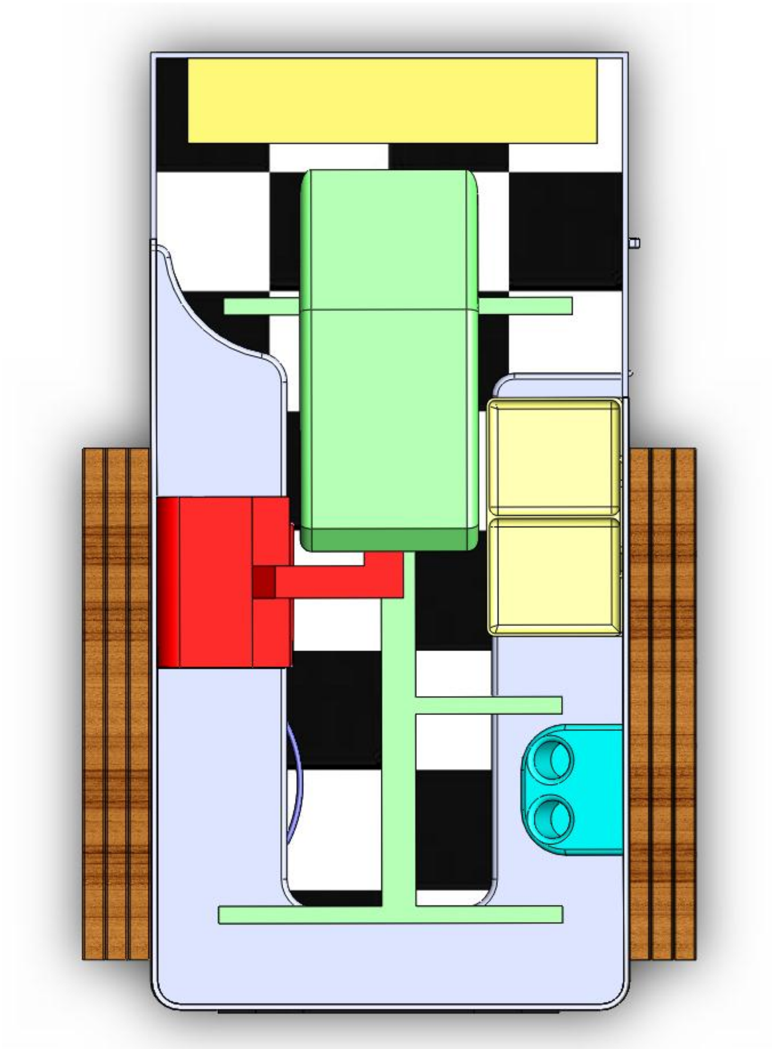


Figure 37. Top-Down View Showing HVAC System

When comparing heat outputs from various sources within the mobile kitchen, the large majority of the heat load is comprised of cooking equipment. In normal kitchen operation, most of this heat load is captured by the exhaust hood and exhausted to the outside. To do this, a large volume of air must be exhausted through the hood to ensure capture of vapor and particulates. However, the all of the air that is being exhausted has already been conditioned to the control temperature of the space. This leads to a large energy waste as all the energy spent conditioning this make-up air is lost as the air is exhausted out of the kitchen.

In our HVAC system, the grill (representing our largest heat load) has its own, separate source of filtered, but unconditioned makeup air. This air is pulled through vents and filters on the side of the kitchen by a small fan. The air is sent through a short section of duct to a diffuser in front of the grill surface. This airflow captures the thermal plume and effluent produced by the cooking process and is then captured by the exhaust hood above the grill. Using unconditioned, filtered air as makeup air for the grill introduces significant energy savings over comparable systems, and reduces the size, and therefore cost, of HVAC equipment needed to serve the mobile kitchen. Figure 38 shows the backside of the grill, in magenta, with the makeup air ducting, in red.

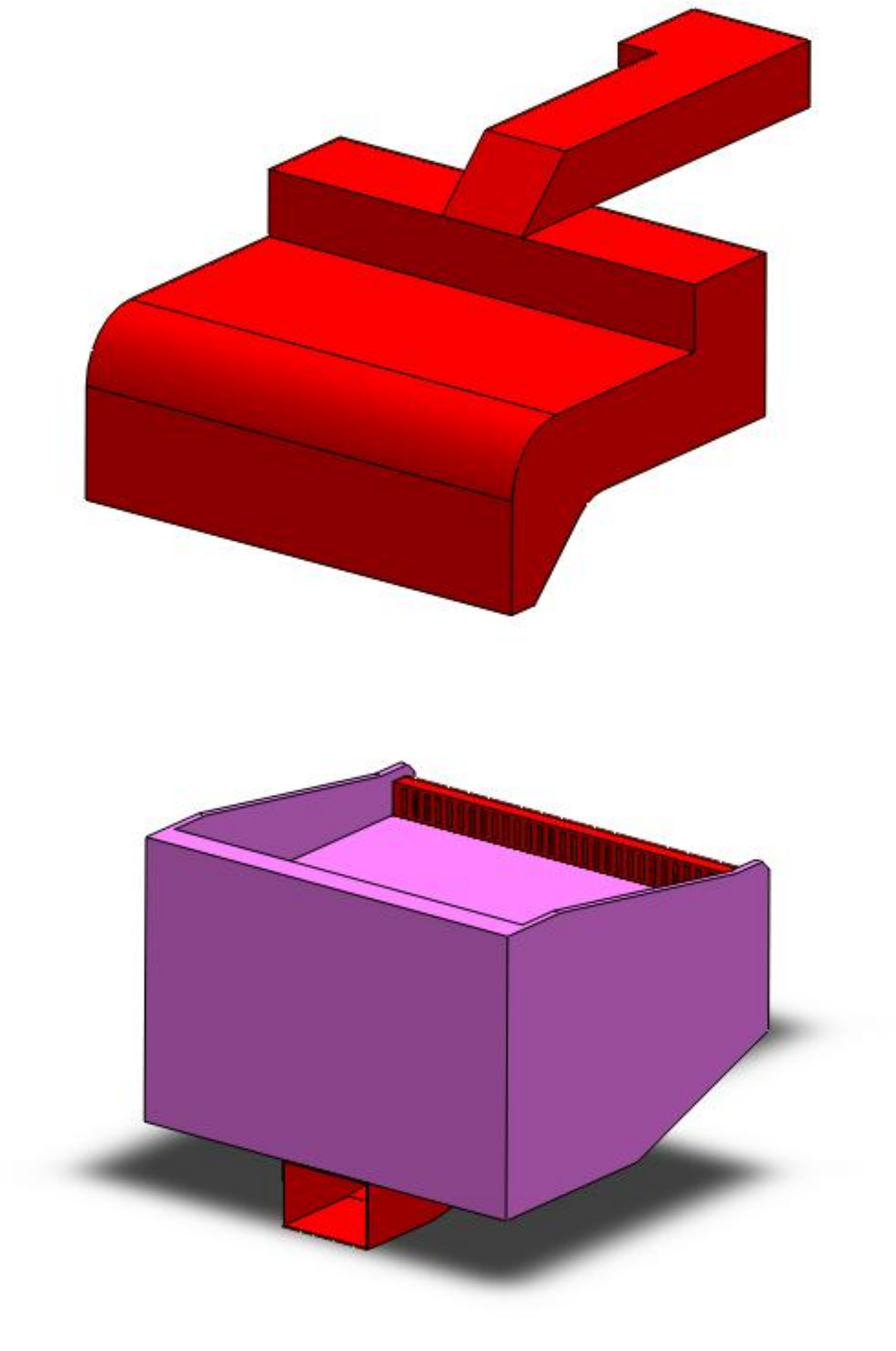


Figure 38. Grill with Make-up Air Ducting and Hood

3.4 Design of Sanitation Enhancing Features

Addressing issues of sanitation in current mobile kitchens was one of the primary objectives of our design and was incorporated in many features of the final design.

3.4.1 Design of Kitchen Surfaces

The most frequently used kitchen surfaces are the countertops, which are used for preparation, staging and storage. The countertops in our kitchen are to be produced out of cold-rolled, 304L Stainless Steel, with a maximum surface roughness of 0.5μm. To avoid the creation of contamination trapping crevices, all surfaces of the countertop with the potential to come into contact with food in normal operation will be welded. Under countertop supports are to be of 304SS, and will be connected using standard fasteners, due to the low potential for food contact and subsequent contamination.

3.4.1 Hand Sanitation

Hand sanitation is a crucial element of any comprehensive food safety program. Employees with dirty hands can spread contamination to products, surfaces and even other employees. It is therefore critical that any mobile kitchen contain provisions for hand washing. It is standard practice to require separate sinks for food preparation and hand washing. Our mobile kitchen includes a sink for food preparation, but takes a different approach to hand washing.

For a standard hand washing program to be effective requires disciplined and motivated employees, which is best achieved through careful personnel selection and risk based training focusing on the consequences of improper hand washing. However, many employees of mobile food kitchens tend to be temporary and receive little training, leading to infrequent or improper hand washing. Therefore, our mobile kitchen will make use of mechanical hand washing devices which remove the human variability from the hand washing process and ensure a consistent result. Food processing facilities switching to mechanized hand washing units see typical hand washing increases of 300% (Gravani, 67).

The unit selected for use in our mobile kitchen is the CleanTech ELF, produced by Meritech, Inc. This unit, shown in Figure 39, can be mounted directly in the countertop.

Figure 39. CleanTech ELF

This unit was selected for its compact dimensions (18"W x 16"D x 23"L), low weight (approx. 50lbs), and low water usage (0.6 gallons per 10 second washing cycle). The 10 second cycle has be clinically proven to be 60% more effective than the average manual hand washing for removing bacteria, all while using only 1/3 of the water (Gravani, 67). This device will allow employee wash their hands very quickly, easily and thoroughly, greatly increasing personal hygiene and food safety.

3.5 Design of Exterior

The exterior of the kitchen was designed with emphasis on aesthetics and ease of maintenance. Unlike most mobile kitchens, the HVAC system is hidden underneath a thermoplastic roof, which can be easily removed for maintenance. The roof gives the kitchen a certain aesthetic appeal and reduces drag during transportation. The color scheme selected for the exterior is a glossy midnight black, the same as the selected chassis. However, this is not shown in the models for purposes of clarity.

The exterior of the kitchen has removable bar-style tables for use by customers. These tables allow customers to eat or apply condiments to their food after ordering, and provide a convenient location to place things such as napkins or extra utensils. Although not shown in the model, these tables are intended to fold into a closed position for transport. Also present on the back end of the kitchen unit is a large LCD Display board. This board serves to display menu items, prices, and the status of orders. These screens are discussed in greater detail in Section 3.7.8.

3.6 Chassis Selection

The chassis for the mobile kitchen is a Ford 2012 E-350 Super Duty Cutaway 176” WB (DRW). This chassis was selected because of the durability and strength. We needed a strong chassis that could support the weight of an entire kitchen and still be drivable. The 176” wheel base was chosen because it was the longest chassis offered in the E-350 line. The chassis needed to be as long as possible to provide enough room for all functions of the kitchen. The 176” wheel base is just enough room to fit everything needed, so it is nearly the perfect size. A frame will be built onto the chassis and this will house the actual kitchen portion. A side drawing with dimensions of the E-350 chassis can be seen in Fig. 40. A top view of the chassis with dimensions is given in Fig. 41. Note that the dimensions given in the drawings are in inches. Fig. 42 shows the actual E-350 chassis. The frame that houses the kitchen would be directly attached to a chassis identical to the one shown.

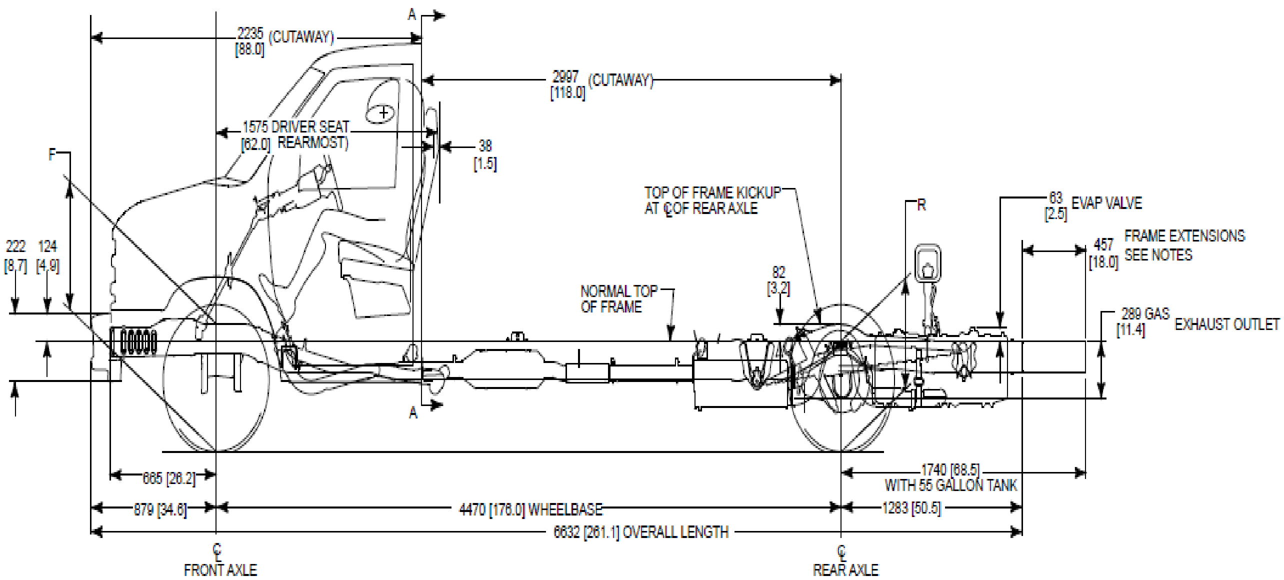


Figure 40. Drawing With Dimensions of E-350 Chassis

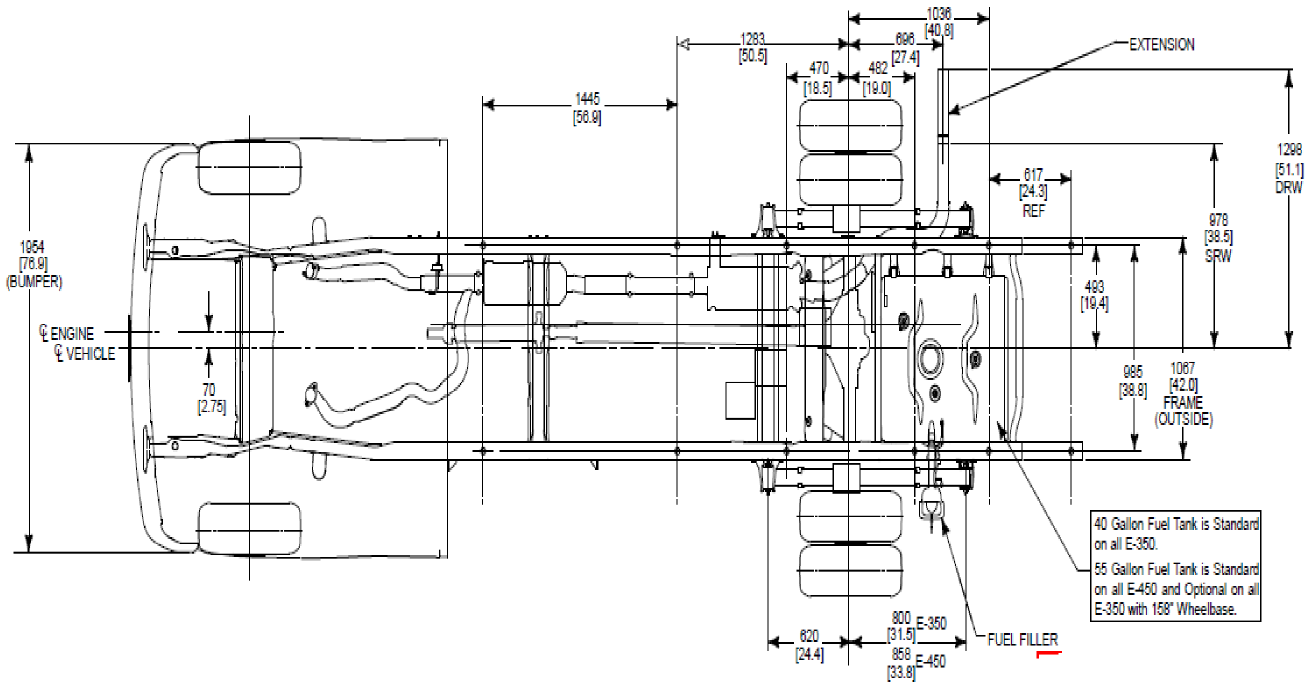


Figure 41. Drawing of E-350 Chassis With Dimensions

Figure 42 - Chassis Selected to Transport Kitchen

3.7 Equipment Selection

Selection of the correct equipment for the kitchen was extremely important. Success of the main functions of the kitchen is contingent upon having the appropriate equipment to accomplish the tasks. Improper equipment could have many negative side effects on the function and efficiency of the mobile kitchen. Such side effects include reduced production, poor sanitation, and increased worker fatigue. All these factors are harmful to the kitchen and can be reduced in severity by selecting equipment that will meet the demands of the kitchen.

Our group made sure that suitable equipment was selected to meet the demands and efficiency concerns of the mobile kitchen. The equipment was selected based on high quality, good reviews, and the capability of increasing production while adhering to the space constraints of the kitchen. Cost was not a constraint while selecting equipment because the best equipment is generally more expensive. We felt that investing in the more expensive equipment would be better for the kitchen because it reduces the risk of faulty or insufficient equipment that would need to be replaced every few years. In the long run, the investment would be better because it ensures that the kitchen can produce at capacity for extended periods of time without malfunction. Overall, the equipment selected for the mobile kitchen improves production and sanitation, reduces fatigue, and properly adheres to the space constraints.

3.7.1 Griddle

The selected griddle to be used is the Garland E24-24G 24" Heavy Duty Electric Countertop Griddle. This selection was based on the ability to increase production in the kitchen. The Garland griddle has a production rate of 300 hamburgers or 460 pancakes per hour. Using this griddle in the kitchen will help efficiency and ease of mass production during times of increased and extended demands. The temperature can be controlled easily and ranges from 100 to 450 degrees F. Having such a wide range of temperature allows for the griddle to cook a wide selection of food, such as hamburgers, hot dogs, pancakes, and chicken. The overall small design of the griddle helps to minimize the space consumed and provides more space for other equipment. The grill top also improves sanitation in the kitchen. It has an easy-to-empty front-loading grease trough, as well as, side and back splashes to protect the countertops and walls. This prevents unnecessary mess and increases the ease of cleaning. It is also made of stainless steel, so the cleaning of actual grill is extremely easy. The cook surface must be hard wired since it does not come with a plug. A transformer will be needed in the electrical circuit to run the 208V grill from the electrical source. A picture of the griddle can be seen below in Fig. 43.

Figure 43. Griddle to Be Used in Kitchen. Courtesy of Garland.

3.7.2 Refrigerator

True Manufacturing TUC-72 19 cu.ft Undercounter Refrigerator was selected to be used in the kitchen. This refrigerator was selected because of its ability to fit under counter tops, while still having enough storage room for the raw food. The under-counter refrigerator was chosen to save space in the kitchen. The fridge will be secured to the wall at the front of the kitchen unit. Storage for dry food and other items will be mounted on top of the refrigerator. This can be done because of the under counter fridge and allows for enough bulk storage space in a small area.

The fridge can cool food products to 32 degrees F, which will be sufficient for all meats and other foods. It is made of stainless steel for easy cleaning and improved sanitation. The fridge has a volume of 19 cubic feet, which is ample space for all sorts of meets. The large volume also means the fridge does not have to be restocked everyday to meet production needs. The True Under Counter Refrigerator can be seen in Fig. 44.

Figure 44. Under Counter Refrigerator Courtesy of True Manufacturing

3.7.3 Storage Cabinets

The storage cabinets to be used in the mobile kitchen are Rubbermaid 24” Wall Cabinets. These cabinets will be mounted to the wall over the under counter refrigerator. These cabinets will hold all the dry food products like bread and canned good. Other products like plates, napkins, and cups will be stored in these cabinets too. Being able to mount the dry food storage over the fridge saved a great amount of space in the kitchen. The Rubbermaid cabinets each hold 5.25 cubic feet of storage. Two of these cabinets will be mounted side by side at chest height above the fridge. Two cabinets will be ample storage for all the dry food products and miscellaneous items.

These cabinets were chosen based on their durability. The cabinets are weather-proof and create an air-tight seal upon closing. This will allow for safe storage of food and prevent the onset of mold. The cabinets also do not rust, dent, or peel. One adjustable shelf is included, allowing for storage and separation of all food items. The cabinet can be seen below in Fig. 45.

Figure 45. Wall Cabinet Courtesy of Rubbermaid

3.7.4 Food Warmer

OCI Elite 30” Warming Drawer was selected to keep the cooked food warm. This product was selected because of its space saving abilities. The warming drawer is able to be mounted under the countertop, freeing up room for other functions. In our kitchen, the warming drawer will be mounted under the final food prep area. This allows for the warm food to be readily put together and packaged for the customer. The warming drawer is also more efficient than using a heat lamp because of the thermostat control allows for precise heating. The temperature can be controlled from 120 to 250 degrees F. being able to control the food warmer with such precision will keep the food hot and fresh while waiting to be served to the customer. The OCI Elite Warming Drawer can be seen in Fig. 46.

Figure 46. Warming Drawer Courtesy of OIC

3.7.5 Sink

The selected sink for the kitchen is the Turbo Air (TSA-2-N) - 42" Two-Compartment Sink. This sink was selected because of its impressive durability and resistance to rust. It is made of high quality 304 stainless steel and is all one piece with no seams. Having a seamless sink improves the sanitation of the kitchen by eliminating places where bacteria can accumulate. The sink also has die-stamped creased drain boards to create positive drainage and avoid standing water and mold. The Turbo Air sink can be seen in Fig. 47. Based on the durability and sanitation conditions, this sink will be sufficient for the small mobile kitchen. A larger industrial sink would be too large for this kitchen and would not provide any additional benefits.

This sink is for washing dishes and food only. A separate sink is needed for hand washing purposes. However, due to space constraints, we decided to replace the sink with a smaller hand washing unit. This is discussed in greater detail in Section 3.4.1.

Figure 47. Sink Courtesy of Turbo Air

3.7.6 Anti-Fatigue Mats

Anti-fatigue mats serve several functions in the mobile kitchen. First, the mats increase production and efficiency of the workers. They reduce the stress placed on the feet and knees of the kitchen workers. This allows the workers to stand for extended periods of time with reduced feeling of fatigue in their legs. As a result, the employees will be more productive. Second, the mats improve the safety of the kitchen. The mats have vented holes that allow for drainage of spilled fluids. Combined with the grip technology, these mats provide improve improved traction and reduce the risk of slipping and falling. This is perfect in the kitchen because the grease and water provides a slipping hazard that the mats help prevent. For our kitchen, we selected the Performa Black GritTuff Mat. These mats will provide a safer and more effective work environment for the employees working in our mobile kitchen. They come and square sections and easily snap together to fit any workspace configuration. The mats can be seen in Fig. 48.

Figure 48. Anti-Fatigue Mats Courtesy of Performa

3.7.7 Cash Register

The Casio QT-6100 Touchscreen Cash Register was selected for use in the mobile kitchen. This specific register was chosen because of its advanced technology that will improve the function of the kitchen. The Casio QT is extremely user friendly and easy to use, making the employee's job easier. The register does not use a Windows operating system, which means it will not crash or get a virus. This takes away the worry of system failure during busy hours. The register can be pre-programmed with different functions. Tax can be automatically calculated into the bill with one quick set up. The register also stores over a hundred prices for items. This allows for easy use by the employee and quick checkout for the customer. The Casio cash register can be seen below in Fig. 49.

Figure 49. Cash Register Courtesy of Casio

3.7.8 LCD Screens

Two LCD screens are needed for our mobile kitchen. One is needed for the display menu and the other is needed for the cook to see food orders. For the advertising screen, the AllSee Technologies 32” HD Digital Advertising Screen was selected. Using this screen as the display allows for easy viewing and quick changing of the menu. Multiple menus can be uploaded and saved on the screens hard drive, meaning the menu can be changed within a few seconds. This allows for the menu to easily change to meet the demands and requests of the customers. Also, the LCD screen provides a well lit display that is much easier to see at night. The LCD display and menu setup can be seen in Figure 50.

Figure 50. LCD Menu Screens Courtesy of AllSee Technology

The other vital screen is needed for the cook to see the orders placed online. This will be mounted in the food preparation area and will tell the chef what has been ordered and what they need to prepare. We selected the ASUS VH242H 24" Widescreen LCD Monitor for this. This screen was chosen because of its compact design and ease of mounting to a wall. The ASUS screen will help to keep the cook organized during busy hours by tracking all orders and marking their completion.

CHAPTER 4. CONCLUDING REMARKS

The Improved Mobile Cafeteria Unit group formed with the objective of addressing the multitude of issues found in current kitchen designs. The team's original focus was on the design of an HVAC system for stationary kitchens capable of both high performance and low energy usage.

The preliminary research for the project began A-Term, and the group quickly identified that most current mobile kitchens suffer from several serious that impair their efficiency and ability to serve customers safely. At this point the team's objective was expanded to include the improvement multiple kitchen systems, including the HVAC system. Specifically, our group chose to focus on improving the ergonomics, the building environment, and sanitation of the mobile kitchen, as these were identified as the largest problem areas in preliminary research.

More extensive research was conducted during B-Term; each aspect of proper kitchen design was explored in depth and was written about in length. During this period the team developed an understanding for the complex interaction between employees and the workplace, and how each affected the safety of both workers and customers. It is the discussion of this critical relationship that begins Chapter 2, providing context for the research to follow.

Using the research gathered in Chapter 2, Team IMCU began work on a new concept for a system of individual mobile kitchens which would operate as part of a coordinated system. The goal of including the kitchen unit within a larger system was to integrate ordering and purchasing food with electronic devices, such as phones and laptops. This allows the streamlining the ordering and food preparation process, eliminating mistakes and increasing customer satisfaction. The MCS allows the customer order and pay on their mobile device, and pick up their order when they arrive at the kitchen's location, simplifying and expediting the experience of mobile food kitchen dining.

With the context of the overall operation of the MCS in mind, the group began design work on the Improved Mobile Cafeteria Unit. This work began with identification of the major constraints on the design itself. The most crucial constraints on the IMCU are mobility, size and functionality. Mobility was the first factor considered, as the system selected for transporting the kitchen dictates the required size of the unit. However, the must also be large enough to hold all the necessary equipment. After selecting the chassis that the kitchen would transported on, design work began on the kitchen unit itself, with a focus on functionality and the interplay of the critical factors effecting safety and productivity that were identified in Chapter 2.

The design of the IMCU was an iterative process, in which previous iterations were updated and often changed significantly. For example, our initial, collapsible design iteration was completely replaced. These iterations can be found in order of their creation in Appendix A. The primary design constraint was space, as we attempted to keep the IMCU as portable as possible. For each iteration, we used Autodesk Revit Architecture to create the layout and a three-dimensional, parametric model of the IMCU. This model was then used to create Solidworks design that included a HVAC system. The final design incorporates many ideas from previous iterations, and meets the design parameters of a mobile kitchen.

Our team would like to see both the design of the Improved Mobile Cafeteria Unit and the Mobile Cafeteria System further improved upon by future project groups. The next step in the design process would be to do a detailed design and component selection for each sub-system within the kitchen unit, such as HVAC, electrical power, and water-storage. The incorporation of this IQP into the design of various sub-systems by future IQP groups would ensure that the overall objectives of improving the safety, efficiency and quality of food served are met. The structural design of the IMCU would be best undertaken by an MQP team capable of detailed analysis of stresses and strains produced by the loads encountered by the kitchen during operation.

Future work on the Mobile Cafeteria System is numerous and open-ended, as our IQP primarily addresses the design of the IMCU. We believe that developing the MCS in conjunction with further design work on the IMCU would yield an end product of high quality, able to deliver food to customers quickly, conveniently and safely. It is our belief that this type of kitchen system would be very profitable when implemented in large cities. The only limitation on producing a kitchen like this is cost. To build the kitchen we designed, it would cost a minimum of $44,000. However, the actual cost will more than likely be higher due to unforeseen and additional costs.

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APPENDICES

APPENDIX A. MOBILE KITCHEN DESIGN ITERATIONS

A.1 Initial design iteration with collapsible roof

While finding background research during A-term, we created our initial design iteration. This design features a collapsible roof, which can be lowered to the height of the countertop. The appliances and storage equipment would be below the countertop, allowing the top half to be lowered. We discarded this design after concluding that the mobile kitchen will not be towed, and therefore the portability of the collapsible design was no longer necessary.

Fig.A1. Collapsed Initial Design

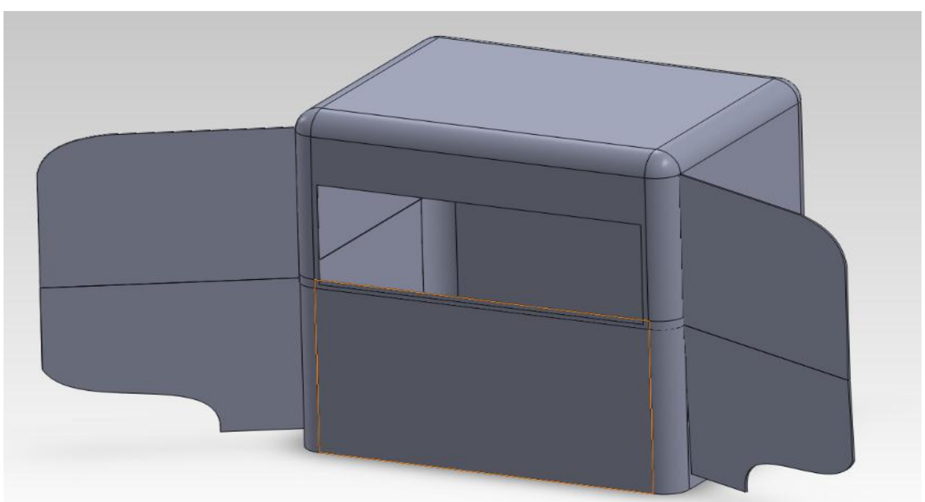

Fig.A2. Expanded Initial Design

A.2. Second iteration with fold-out tables and storage area

Our next design iteration was a chassis-mounted kitchen featuring fold-out tables. A walking aisle separated the two counters, and allowed workers to access a serving area. Tables on either side of the mobile kitchen could be folded out to allow customers to sit and enjoy their meal. In our final design, we adjusted the positioning of the appliances and removed the storage and support equipment area in favor of a smaller bulk storage area.

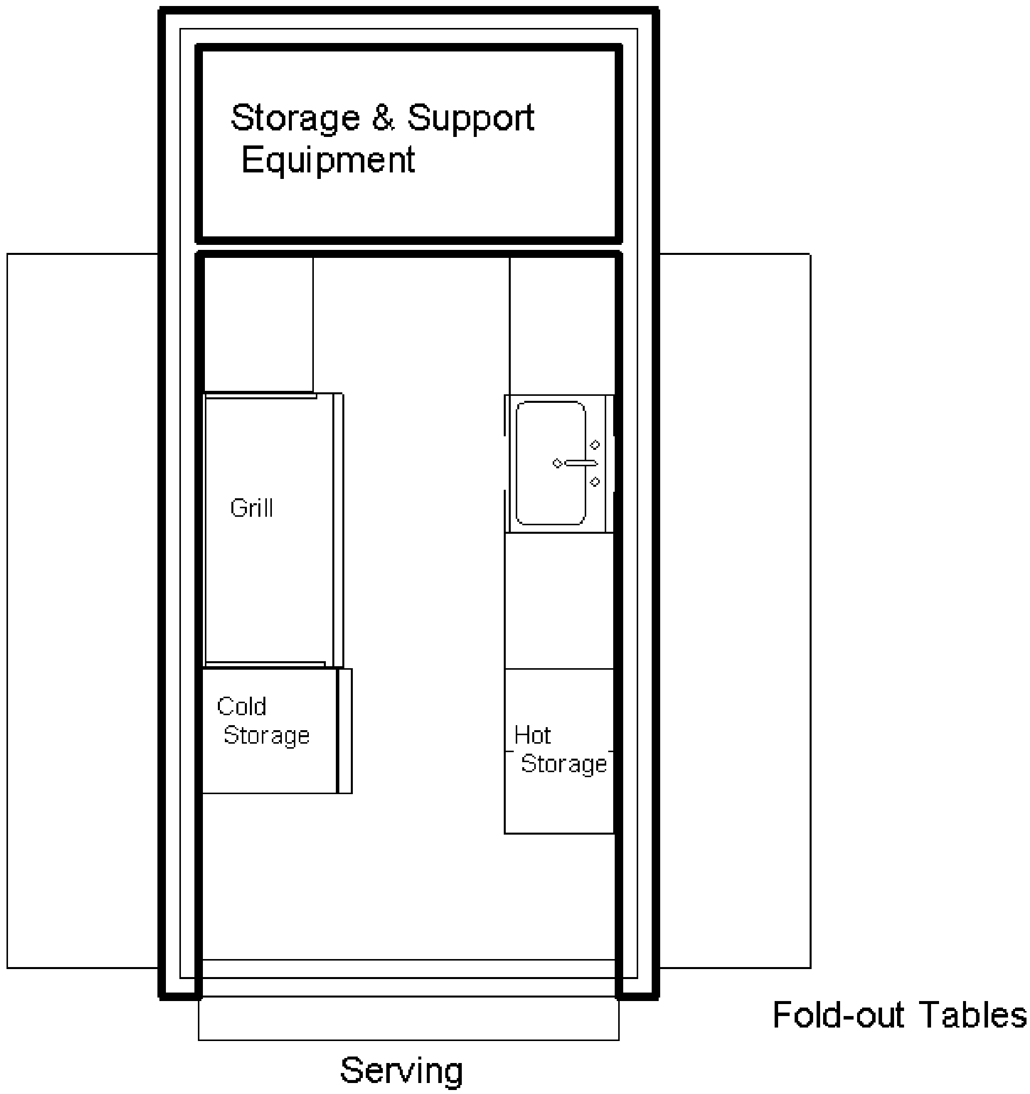

Fig.A3. Layout of Second Design Iteration

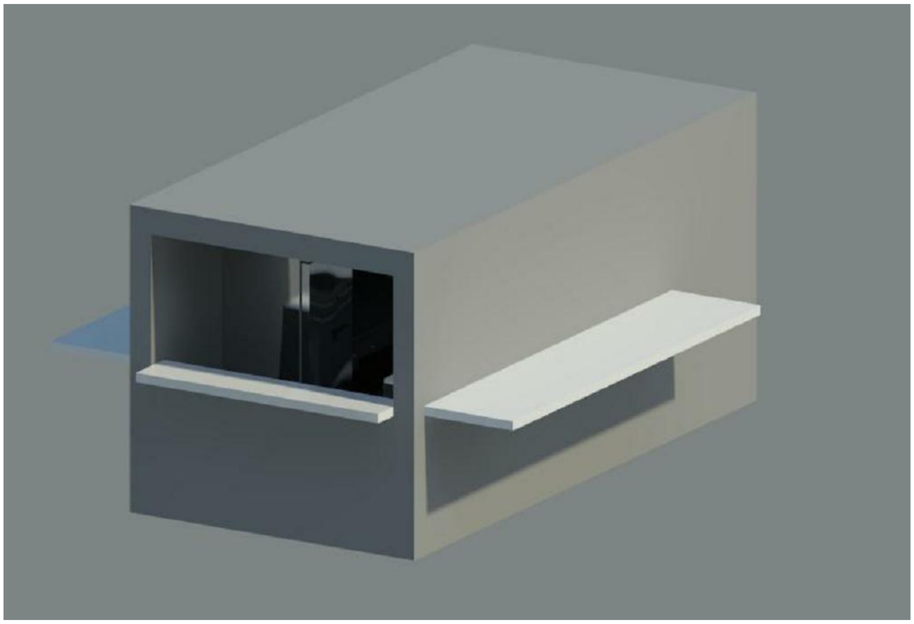

Fig.A4. Exterior View of Second Iteration

Fig.A5. Interior View of Second Iteration

A.2. Third iteration with added HVAC system

The third iteration expands on what was designed in the second iteration. An HVAC system was added to the roof of the mobile kitchen, and the refrigerator and bulk storage were repositioned to save space.

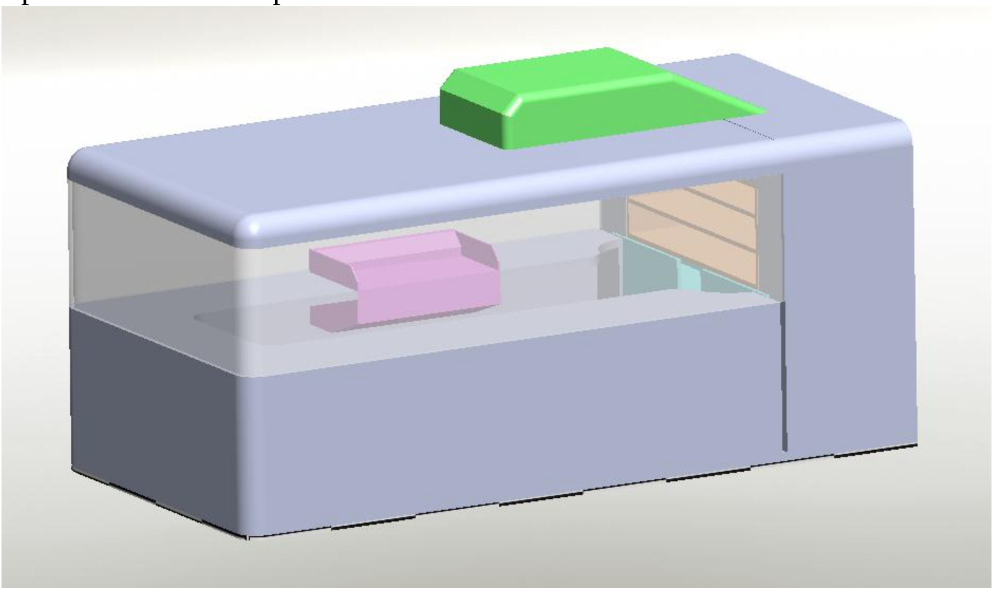

Fig.A6. Third iteration exterior view

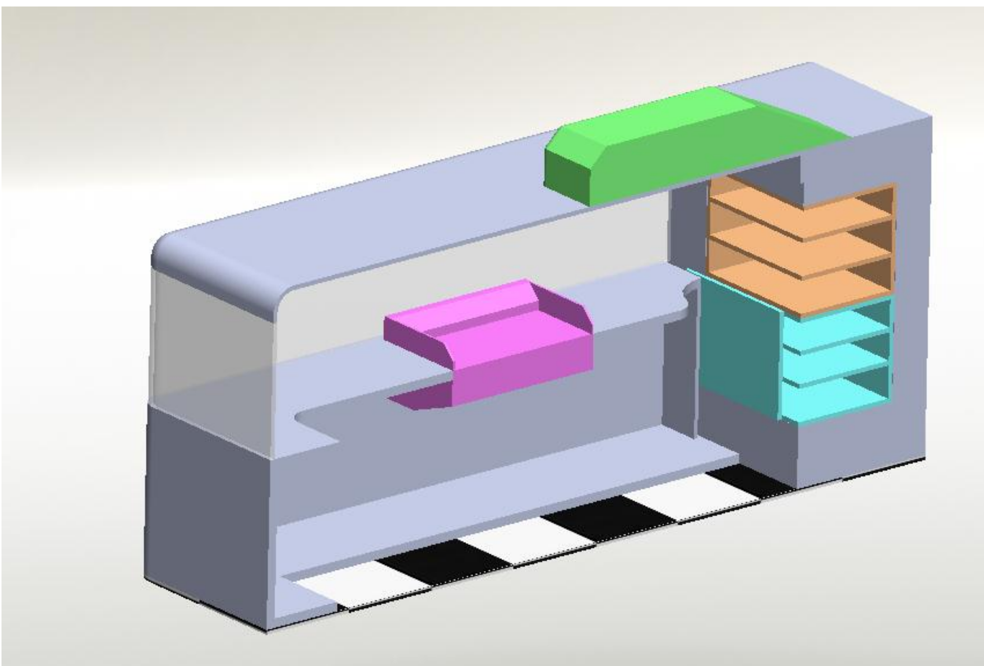

Fig.A7. Third iteration cross-sectional view